

**COMPARATIVE EVALUATION AND ECONOMICAL SELECTION
OF LATERAL FOR ABBREVIATED SPRINKLER AND
MICROSPRINKLER IRRIGATION SYSTEM FOR CLAY LOAM SOIL**

*Thesis submitted to the University of Allahabad
for the award of the degree of*

DOCTOR OF PHILOSOPHY
(Faculty of science)

by

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CERTIFICATE

This is to certify that the thesis entitled "COMPARATIVE EVALUATION AND ECONOMICAL SELECTION OF LATREAL FOR ABBREVIATED SPRINKLER AND MICROSPRINKLER IRRIGATION SYSTEM FOR CLAY LOAM SOIL "submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in soil science, of the Allahabad Agricultural Institute – Deemed University, Allahabad, Uttar Pradesh, is a record of bonafide research carried out by Mr. Derrick Mario Denis, under my guidance and supervision .No part of this thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of investigation have been duly acknowledged.

A handwritten signature in black ink, appearing to read 'Rajendra B. Lal', with a date '17/5/2013' written to the right of the signature.

Prof.(Dr.) Rajendra B .Lal

Former Professor and Head

Department of soil And Environmental Sciences

Presently

Vice Chancellor

Allahabad Agricultural Institute - Deemed University

**TO
MY
PARENTS**

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I am gratified to avail of this opportunity to liberate my feelings and emotions towards one and all who have contributed their bit for the successful completion of this study. I, with sincere respect thank my guide **Prof. R. B. Lal**, Professor, Soil and Environmental Sciences and Vice-Chancellor, Allahabad Agricultural Institute Deemed University for his blessings and guidance rendered throughout the course of this study. I acknowledge and appreciate the valuable suggestions suggested by Prof. M. Imtiyaz, Professor and Head, Department of Soil, Water, Land Engineering and Management, Professor D. P. Sharma, and all faculty members of the Department of Soil and Environmental Sciences and Prof. S.S. Singh, Dean, College of Agriculture. I am highly grateful to Prof. Gurmit Singh, Dean, College of Computer Science and Mrs. Seema Singh, Assistant Prof. Department of Computer Science for their untiring help and guidance in the development of the computer software. I am thankful to Dr. Ashok Tripathi for his help rendered in submission of this thesis. I will always remain grateful to my parents, brothers and sisters who have always stood by me at all times.

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Once again I thank my Lord and Almighty for giving me one more opportunity to praise and thank Him for bestowing his blessings on me and giving me the most beautiful gift, my son Emmanuel.

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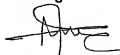
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LIST OF SYMBOLS

A	Area
ASAE	American Society of Agricultural Engineers
ASCE	American Society of Civil Engineers
a	Constant
a (J)	Values of original catch can pattern
b	Constant
C	Friction coefficient
cm	Centimeter
C _p	Initial cost of Lateral pipe
C _s	Initial cost of sprinkler heads
C _r	Initial cost of risers
C _c	Initial cost of couplers
C _e	Cost of electricity
Ca 1	UC above the general mean
Ca 2	UC below the general mean
CRF	Capital recovery factor
C _f	Cost of fuel
SS	Sprinkler spacing
Di	Inner diameter
S _s	Lateral spacing
@	Decimal equivalent annual rate of energy escalation
°C	Degree centigrade
cae (e)	Equivalent annualized cost,
EC	Energy cost
f	Correction factor
F _c	Fixed cost
h _{fl}	Head loss due to friction in pipe
h _a	Total head at sprinkler inlet

hi	Inlet pressure head
hr	Sprinkler riser height
Hc	Coefficient for height
hp	Depth of water
hw	Height of water
h	Hours
ΔH	Friction head loss
HP	Horse power
I	Infiltration rate
iP	Dummy variable
iQ	Dummy variable
Ic	Initial cost
K	Hydraulic conductivity
Kor	Value of observation in rows of overlapped pattern
Koc	Value of observation in column of overlapped pattern
Kr	Value of observation in rows of original pattern
Kc	Value of observation in column of original pattern
kWh	Kilo watt hour
Kg	Kilo gram
K	Constant
L	Liters
Ma	Mean of the group above the general mean
Mb	Mean of the group below the general mean
m	Meter
mm	Millimeter
md	Mean depth of observation
mha	Million hectare
n	constant
no	Number of observation
Na	Number of observations above the general mean
Nb	Number of observations below the general mean

Ns	Number of sprinklers
NT	No tillage
P	Operating pressure
pH	Negative logarithm of the hydrogen ion activity of a soil
Pw (e)	Escalating energy factor
q	Discharge
ri	interest rate
rpm	Revolution per minute
s	Second
Sd	Standard deviation
Ta	Sum of observation above the mean
t	Annual use per hour
Tb	Sum of observation below the mean
Th	Number of working hours
Tc	total cost
Ty	Hours/year
UCC	Christiansen uniformity coefficient
UC (f)	U.C. on flat land
UCW	U.C Wilcox
UCL	U.C. Linear
UCH	U.C. Hart
USA	United States of America
x	Mean
Xa	Absolute deviation above general mean
Xb	Absolute deviation below general mean
Z	individual depth of catch can
%	Percent
θ	Nozzle angle
<	Less than
>	Greater than
MP	Mould board Ploughing

CHAPTER – I

INTRODUCTION

INTRODUCTION

Water is a prime, natural, indispensable, finite and vulnerable resource. Now the need for portable water is escalating because of rapid industrialization and increasing population especially in the region where water is scarce. Worldwide agriculture uses 69% of total water available. India uses about 90% of water for agriculture. By present estimate, the ultimate potential through conventional sources, is likely to irrigate about 12m ha (Survey of Indian Agriculture, 1996). The irrigated area has increased from 22.6m ha in 1951 to about 90 m ha at the end of 1995-96. Surface irrigation is adopted in 99% of the irrigated area. Sprinkler irrigation is used in about 0.6m ha (Survey of Indian Agriculture, 1996). Sprinkling irrigation represents the broad class of pressurized irrigation method, in which water is carried through a pipe system to a point near which it will be jetted through the air to spread it from the pipe network across the soil surface. The usual goal of sprinkling is uniform watering of an entire field.

The need for the study of the comparative evaluation and economical selection of lateral for abbreviated sprinkler and micro sprinkler irrigation system for clay loam soil is interesting because of the hydration and swelling characteristics of this type of soil. In normal circumstances, clay particles are never completely dry. Even after being placed in an oven at 105⁰ C for 24 hrs., which is the standard for drying soil material, clay particles still retain appreciable amount of adsorbed water.

The strong affinity of clay surfaces for water is demonstrated by the hygroscopic nature of clay soil i.e. their ability to adsorb and condense water vapor from the air. So called air-dry soil, is commonly found to have a mass wetness of several percentage, the exact percentage depending of course upon the kind and quality of clay present, as well as upon the humidity of the ambient air.

In the oven dry state, the water associated with clay is so tightly held that it can be considered a part of the clay itself. As clay becomes increasingly hydrated, the water film surrounding each particle thickens and the water is more loosely held. The entire physical behavior of clay containing soil mass is strongly influenced by the degree of hydration.

The time dependent volume increase in clay and clay-sand mixtures is due to low permeability of clay systems. The eventual swelling is seen to depend on the amount and nature of clay present. This swelling causes the clogging of soil pores and reduction in permeability.

This phenomenon is of great importance in special circumstances when sprinkling over clay loam soils are considered. When a hydrated body of clay is dried a process opposite to swelling occurs, namely shrinkage.

The infiltration of water in the case of sprinkler and micro sprinkler is that of unsaturated infiltration. Most of the process involving soil-water interactions in the field, and particularly the flow of water in the rooting zone of most crop plants, occurs while the soil is in unsaturated condition. Unsaturated flow processes are in general complicated and difficult to describe qualitatively. Since they entail changes in the state and content of soil water during flow. In recent decades, however, unsaturated flow has become one of the most important and active topic of research in soil physics and this research has resulted in significant theoretical and practical advances.

While watering of an entire field it is necessary to analyse the economics of the irrigations system. The selection of the most economic irrigation system depends upon the size of the laterals and the type of sprinklers to be used for irrigation. The size of lateral and type of sprinkler in relation to the soil type plays a major role in recommendation of the actual size of laterals to the farmers to economize the pressurized irrigation system.

To select the most economical lateral diameter for the sprinkler system it is necessary to simulate the sprinkler precipitation under field conditions using single leg catch can data to determine the uniformity of application using the existing models. It is also necessary to develop abbreviated methods to simulate the uniformity of application of water in catch can as well as the areal distribution of water in the soil.

Water application uniformity is an important measure of performance used in the design and evaluation of sprinkler irrigation systems. Procedures to determine the distribution of water from sprinklers are given in ASAE standard S30 (ASAE, 1983) but, as the title of the standard (Procedure for sprinkler Distribution Testing for Research Purposes) suggests, its application is preferential to research. Less time consuming and less involved procedures are needed by field engineers, technicians and growers so that they may screen a large number of systems.

ASAE standard S398T (ASAE, 1983a) further specifies collector spacing and position relative to the sprinkler. For sprinkler throw radii less than 3m as in the case of micro sprinkler maximum recommended spacing is 0.5m and for throws greater than 12m, spacing increases to only 1.5m. However maximum errors in estimating mean application depth was only 3.2% for a wider 3.0m grid on a 9.1m by 15.2m sprinkler spacing. (Davis 1966). Data collected for 0.6m collector grid was used as the standard to judge accuracy. Further Christiansen's uniformity coefficient (1942) was not affected by collector spacing for three of the four patterns tested. Uniformity was greater by 5% when 1.8m to 3.0m spacings were used for fourth, less uniform, patterns. Thus for the conventional grid orientation of cans, spacing might be doubled without introducing significant error in mean water application depth or uniformity for relatively uniform distributions.

Davis (1966) also estimated mean water application depth from one row or two rows of collectors placed at right angles to the lateral near the mid

point between sprinklers. These results were then compared to a full-scale two dimensional grid evaluation. Error up to 20% were found for single row and to reduce errors to less than 5%, two row, with a collector spacing along each of the two rows of 10% of the laterals spacing, were recommended, uniformity calculated from the rows was not given and therefore not compared to uniformity of the full scale grid results. This would have been in an attempt to abbreviate the evaluation.

Irrigation efficiency is a concept used intensively in irrigation system design and management. It can be divided into two components, uniformity of application and losses. If either uniformity is poor or losses are large, efficiency will be low. The uniformity of application is of primary concern in the sprinkler irrigation design procedure. The parameter that is widely used to evaluate sprinkler uniformity is the coefficient of uniformity developed by Christiansen (1942). Computer simulation of uniformity and water application depth is a function of sprinkler spacing along the main line and lateral Wallender and Ohira (1987).

To accomplish the ultimate in efficiency in applying irrigation water moisture should be supplied to the crop as per the demands at various stages of growth. Furthermore, these quantities would be governed by the capacity of any given soil to retain water for crop use. While applying the water, losses of water during irrigation period would need to be reduced to a minimum. The application of water through sprinkler irrigation reduces the moisture stress of the crop root area to a large extent. However the water application being controlled, only the required amount of water can be supplied in the system. Application of water to soil with sprinkling irrigation is based on the principle of no runoff. In other words the water applied with a sprinkler system properly designed, will be absorbed by the soil as it is applied and without movement of water from one part of the field to another (Sprinkler Irrigation 1955).

It is the ability of a soil to serve as reservoir for water and the nutrients dissolved in it, which must bridge the gap between the plant requirement, which are practically incessant, and the supply of water which is intermittent and may be infrequent. But the soil is a leaky reservoir, which losses water downward by leaching and upward by evaporation. To manage the system so as to maximize water use efficiency, we must monitor the balance of incoming water versus out going water and the consequent change of moisture as well as nutrient storage in the root zone.

Infiltration is the passage of water into the soil surface. The movement of water into soil may be limited by any restriction to the flow of water through the soil profile. Although such restriction often occur at the soil surface. It may occur at some point in the lower range of the profile. The most important items influencing the rate of infiltration have to do with, is soil and the cover on the soil surface, but such other factors as soil moisture, temperature and rainfall intensity are also involved.

The other major factors affecting the infiltration of water into the soil are the initial moisture content, condition of the soil surface, hydraulic conductivity of the soil profile, soil structure and texture, porosity, degree of swelling of soil, vegetative cover, duration of irrigation or rainfall, viscosity of water, the depth of water on the surface, specific gravity of soil grains, permeability, plasticity index, tillage practices, void ratio, entrapped air and salt content of water. The antecedent soil moisture content has considerable influence on the initial rate and the total amount of infiltration. Both decreasing as the soil moisture content rises. The infiltration characteristics of the soil is one of the dominant variable influencing irrigation. The amount of moisture already in the soil greatly influences the rate at which water enters the soil. When the moisture content of the soil is low, the infiltration rate is quite high, as the irrigation application continues, the surface soil gradually becomes saturated and the infiltration rate decreases until it becomes nearly constant.

The constant or nearly constant rate at which the soil takes in water after an extended period of time is the basic infiltration rate.

The knowledge about infiltration is of great importance to an irrigation engineer for applying right amount of water at right time. The knowledge of infiltration rate under field condition is also important in the designing of a farm irrigation system and determining the time required to irrigate a given plot of land to required depth soil of various structures have varying ability to retain water except for required periodic leaching, any irrigation beyond the field capacity of the soil is an economical loss. The primary aim of any irrigation is to irrigate the root zone depth.

A balance between depth of irrigation, frequency of irrigation, operating pressure and moisture content at different depth is very essential to prove the acceptability of the irrigation system. The pressure at the sprinkler along with the area of coverage (stream size) and soil type explains the depth of water achieved, and the number of irrigation needed.

Generally it is found that large area of clay loam soil exists in and around Allahabad Agricultural Institute. In recent years it has been observed that during summer season the level of ground water also reduces drastically. Sprinkler irrigation is a new concept in this region. Studies based on actual field condition for the determination of infiltration characteristics under overhead sprinkler and micro sprinkler are not sufficiently available.

The most economical size (or combination of sizes) of lateral pipe will be reasonable when a balance is maintained between the annual fixed cost of owning the pipe and the annual operating cost of pumping water through it. The optimum life cost cycle of a system helps in selecting a diameter of an irrigation water supply line. If a very small pipe used, the fixed cost will be low, but the operating (Energy) cost of over coming friction loss in the pipe will be relatively high. Only a limited set of discrete pipe diameters are available that would be physically or logically suitable for a given flow rate. Therefore, only

these diameters needed to be checked to determine which one would give the lowest total annual fixed plus annual energy cost.

In our region the studies on economical selection of lateral used for sprinkler and micro sprinkler irrigation and their comparative evaluation are limited. It is also necessary to develop abbreviated methods to obtained uniformity of application of water. Information related to comparative evaluation and economical selection of lateral for abbreviated sprinkler and micro sprinkler irrigation system for clay loam soils does not exist in this region. As government is also paying special attention for sprinkler irrigation by providing subsidy to farmers, there is a need of research work in this area for better utilization of government funds to adjudge proper installation of sprinkler and micro sprinkler system.

Considering these points a problem "Comparative evaluation and economical selection of lateral for abbreviated sprinkler and micro sprinkler irrigation system for clay loam soil" was undertaken with the following objectives:

1. Development of computer software for computation of overlapped pattern and determination of uniformity coefficient.
2. Evaluation of abbreviated overhead sprinkler and micro sprinkler uniformity.
3. Determination of time of irrigation for crops grown in clay loam soil for overhead and micro sprinkler irrigation system.
4. Comparative study of economical selection of overhead sprinkler and micro sprinkler for clay loam soil.

CHAPTER – II

REVIEW OF LITERATURE

REVIEW OF LITERATURE

This chapter deals with the review of research work done in the area of uniformity of sprinkling irrigation along with computer application to determine uniformity coefficient and abbreviated uniformity coefficient and economics of sprinkler irrigation systems. It reviews the research work done in the field of water movement in clay loam soil.

Johson (1877) pointed that the tillage gives a healthy and well-aerated root bed and also that tillage contains rainwater against drought. The conservation of moisture was affected by increasing the infiltration capacity of soil. He further mentioned that the major fundamental objectives of cultivation are to maintain good tilth during the crop growth, rapid infiltration and aeration are also important aspects of cultivation.

Kostiakov, A.N. (1932) presented following equation describing infiltration of water into soil.

$$I = Kt^{-n}, (0 < n < 1) \quad 2.1$$

To get the accumulated depth of water or cumulative infiltration, the above equation is integrated with respect to time and the following equation is obtained.

$$I = K \cdot (-n+1)^{-1} \cdot t^{(-n+1)} \quad 2.2$$

Where

I = infiltration rate, cm/hr

K = hydraulic conductivity, m/day

T = time, hrs

n = constant

The demerit of Kostiakov's equation is that the infiltration rate will approach zero after long period of time which is physically not correct.

The merit of this equation is that it adequately represents, infiltration over limited time, which is generally satisfactory in irrigation practices. The above two equations (2.1) and (2.2) of Kostiakov, if plotted on a log log paper, will be straight lines.

Christiansen (1937) presented an impression to initiate the degree of uniformity of water distribution for a sprinkler system.

Christiansen (1941) conducted about 300 tests on sprinkler and analyzed the data to determine the uniformity of distribution for various spacing and consideration of geometric patterns to determine desired patterns and their relation to spacing.

He concluded that:

1. Uniformity of distribution of water from sprinklers varies greatly depending upon pressure, wind, rotation of sprinklers, spacing and many other factors.
2. Nearly uniform application is possible with proper sprinkler pattern and with proper spacing of sprinklers.
3. Sprinkler patterns are approximately conical where a maximum application occurs near the sprinkler and decreases gradually to the edge of the area covered, produce a uniform application when sprinklers are not further apart than 55 percent to 60 percent of the diameter covered.
4. For wider spacing a pattern for which the application is uniform for some distance from the sprinkler and then tapers off gradually but the maximum uniformity obtained decreases with the spacing for all spacing greater than 50 percent of the diameter covered.

5. For spacing greater than 50 percent of the diameter and with equivalent area covered by each sprinkler, a more uniform application can be obtained with an equilateral triangle arrangement of sprinklers than with a square or rectangular arrangement.

Benani and Hore (1954) defined a new uniformity Co-efficient 'A' as:

$$A = Ca_4/Ca_2 \quad 2.3$$

Where,

$$Ca_4 = Mb - Xb/Nb \quad 2.4$$

Where,

Mb = Mean of the groups below the general mean

Nb = Number of observation below the general mean

Xa = Absolute deviation from, Ma of the graph of individual reading below general mean.

Xb = Absolute deviation from, Mb of the graph of individual below general mean.

They observed that $Ca_1/Ca_2 = 0.6$ for distribution pattern and hence to express 'A' as a percentage, it is multiplied by a factor (100/0.6) equal to 166, thus

$$A = 166 (Na/Nb) (2Tb + Db Mb) / (2Ta + Da Ma) \quad 2.5$$

Where,

Ta and Tb = Sums of observations above and below general means respectively.

Da and Db = Difference between number of reading above and below general mean respectively.

Ma = Mean of the groups above the general mean

Na = Number of observations above the general mean

Wilcox and McDongald (1955) evaluated the uniformity coefficient of sprinklers by using the sum of the squares of deviations from mean, UCW is given by the following formula:

$$UCW = 100 (1-sd/x) \quad 2.6$$

Where,

UCW = Wilcox uniformity coefficient

Sd = The standard deviation of the sample

X = Mean of the sample

Scott and Correy (1957) reported that sprinkler and laterals spacing influence the uniformity of water distribution. They suggested that wter distribution can be improved under high wind condition by closer spacing of sprinkler and laterals.

Hart (1961) developed a method to match pattern parameters with irrigation requirements. An attempt was made to demonstrate their interrelationship based on the assumption of normal distribution under an overlapped sprinkler pattern, he pointed out that the absolute value of the mean of deviation (x) equals approximately 0.798 times the standard deviation of the sample if the sample has normal distribution. By substituting this value in Equation 2.3 the following expression for uniformity co-efficient UCH was obtained.

$$UCH = 100 (1-0.798 Sd/x) \quad 2.7$$

With the assumption that the observations were normally distributed under an overlapped pattern, it is possible to design parameters which would determine the fraction of an irrigated area that will have a given minimum application or the fraction of an area that will have an application rate between two limits.

He presented the computation of an overlapped pattern from an original pattern. He developed a mathematical relationship between the overlapped pattern and the original pattern. The following expressions were developed:

$$A(J), J = 1, \text{ no} \quad 2.8$$

$$B_{ij} = \sum a \text{ no} \quad 2.9$$

$$I = 1, 2, 3, \dots, K \text{ or}$$

$$J = 1, 2, \dots, K_{oc}$$

Where

$A(J)$ = values of original pattern

no = number of observations

b_{ij} = values of overlapped pattern

kor = number of observations in rows of overlapped pattern

koc = number of observations in columns in the overlapped pattern

Kr & Kc are related similarly in the original pattern.

From the standpoint of the computer, it was convenient to consider the data in an original pattern as one dimensional array. They were read in rows and stored in continuous fields. The values were observed by a subscript, which varies from 1 to no.

Where,

$$N_o = k_r \cdot k_c \quad 2.10$$

The equation 2.10 can be rewritten as follows:

$$B_{ij} = \sum a_{is} \quad 2.11$$

The subscript for 'is' has the form

$$I_s = i_t + k_r \cdot k_o c (i_Q - 1) + K_r \cdot (J - 1) \quad 2.12$$

$$I_t = I + K_o r \cdot (i_p - 1) \quad 2.13$$

I_p and i_Q are dummy variables.

The program was used for detailed analysis of a test or to determine if a test met certain minimum distribution requirements.

Davis (1966) presented an analysis of parameters for describing uniformity of water distribution from sprinklers in relation to the density of sampling stations. Data for the analysis were collected from the sprinkler system employing 10.6 cm to 7.62 cm diameter lateral pipe lines, each 15.24 m apart and operated simultaneously. Eight 4.3656 mm single nozzle rotating sprinklers were placed 9.14 m apart on each lateral on 45.72 cm riser. The central 7.62 x 127 cm rectangular area was selected for sampling in order to include the influence of surrounding sprinklers.

Pair (1968) studied water distribution under sprinkler irrigation. He calculated the Christiansen coefficient of uniformity. The factors affecting water distribution were nozzle size, nozzle angle, rotatory speed, number of nozzle, sprinkler head, spacing on the lateral, spacing of the lateral among the main pipe and the height of the sprinkler above the crop.

United States Department of Agriculture (1968) reported certain pattern characteristics that changes as nozzle size and operating pressure

changes. Each sprinkler had an optimum pressure for each nozzle size. It was found that in selecting nozzle sizes and operating pressure for a required sprinkler discharge, the different pressure affect the pattern as follows:

1. At the lower side of the specified pressure range for any nozzles, the water is broken up into large drops. When pressure falls too low, the water from the nozzle falls in a ring at a distance away from the sprinkler, thus giving a poor moisture distribution pattern.
2. On the high side of the pressure range, the water from nozzle breaks up into finer drops and sets around the sprinkler. Under such conditions the pattern is easily distorted by wind movement.
3. Within the desirable range, the sprinkler should produce the distribution of water uniformity.

Reynolds and Pai Wu (1972) reported that skewness and kurtosis can be related to sprinkler uniformity coefficient with a value of 70 percent or less. The distribution of low uniformity data is generally positively skewed. Low values of the uniformity coefficient (lower than 40 percent) result in large positive values of skew. Skew and kurtosis do not affect the values of uniformity coefficient data are narrow and step. If a system is designed with high uniformity coefficient the effect of skew and kurtosis will be very small and can be neglected.

Rochester (1973) presented the utility of computer graphics in sprinkler system design. This computer graphics program was developed at Aarbum University to demonstrate sprinkler characteristics and the effect of various design criteria on the resulting water distribution.

Tyagi and Mohanty (1974) studies the effect of sprinkler arrangement on uniformity of sprinkler irrigation and found that triangular arrangement of sprinkler increased the uniformity coefficient by 7 percent as compared to rectangular arrangement.

David (1978) studied the use of linear regression to describe sprinkler distribution pattern. The linear fit was found to approximate the distribution very well in wide range. A new co-efficient UCL is suggested for practical use. In the higher quality distributions, the linear regression model estimated the actual field data as well as the normal model. However, in lower quality distribution ($UCC < 55.0$) the linear regression model proved significantly better than the normal model in its estimates.

Ken Soloman (1979) analysed the coefficient of uniformity test results for a common medium sized agricultural sprinkler. Uniformity test results were found to very significantly was under similar test conditions. The amount of variation to be anticipated in measured uniformity coefficient values were correlated with the uniformity coefficient values itself. Factors influencing this variation were discussed, and the statistical significance of such variation was explored.

Ken Soloman *et. al.* (1980) presented a method identifying characteristics distribution pattern shapes for a sprinkler. The process involves normalizing distribution test data and then applying the k-mean clustering algorithm to the resulting dimensionless curves. The method yields prototypical distribution pattern shapes as well as an indication of the range of the nozzle size and sprinkler operating pressure, over which the prototype shapes may be considered valid. The method was applied to data for atypical gun type sprinkler. Three pattern shapes were found to be representative of the performance of this types of sprinklers.

Ronald *et. al.* (1980) studied the sprinkler uniformity models. The objective was to study the β distribution characterization of water application depth of sprinkler irrigation system, to evaluate the goodness of fit to the linear normal and β models to water application depth and suggested recommendations for the selection of appropriate statistical criterion for the use in specific situations. The UCC, UCW and UCH were evaluated and the

linear, normal and β statistical models were fitted to 2450 over lapped sprinkler pattern, which had widely varying uniformity co-efficient.

I. Pal Wu and Harris (1983) stated that the energy gradient line of sprinkler irrigation (or sub main) can be expressed by a dimension less energy gradient curve. They found that the pressure variation along a lateral (or sub main) can be determined by combining the friction drop and energy gain (or loss) by slopes. They also developed a design chart for uniformity down slope situation. A simple table was presented by them for non uniform slope situation calculations. Their primary objective was to include slope effects in the design of sprinkler system.

Chen and Wallender (1984) presented simulated and graphical methods to economically select spacing and orient functions of sprinkler spacing also the lateral and between laterals. They found that when sprinkler spacing increases, uniformity and depth of water applied decreases as the price of the crop falls and the cost of equipment and applied water rises. From these relations an equipment cost function was introduced into a profit function which, when solved, gave uniformity and depth of water application.

Gohring and Willender (1987) had optimized the annualized profit for a hand move aluminum sprinkler irrigation system using sprinkler spacing, applied water and characteristic pressure as independent variables under no wind condition. Income is calculated using a cotton water production function and expenses include water, energy, pipe, sprinkler and pumping plant costs. The algorithm accounts for variations in pressure throughout the water delivery system and in averaged local yield for a level with pressure to maintain profitability for the sprinkler tested. Optimum values of applied water are 5cm to 15cm below peak yields depths.

Yuping and Hills (1987) presented a developed microcomputer program in IBM Basic which calculates the coefficient of uniformity and the average depth of irrigation water applied with a linear move machine. The

program variables include machine characteristics, sprayer spacing and machine speed, water distribution data are from either two rows of catch cans or a single sprayer distribution patterns.

Wallender and Ohira (1987) presented computer simulation of uniformity and water application depth as a function of sprinkler spacing along the mainline and lateral which was used to study the abbreviated method of evaluating performance of periodic and solid set sprinkler irrigation system under no wind conditions. They used full-scale two-dimensional grid layout of collectors, which was abbreviated to 10 collectors equally spaced between two sprinklers along the lateral. According to the simulation, the abbreviated method can replace full-scale evaluation when mainline spacing is less than $0.65 - \text{wetted diameter } (0.65 D)$. They further recommended that since the lateral spacing is not to exceed one half mainline spacing, lateral spacing is at most $0.65/2$. They found that agreement between abbreviated and full-scale results applies to laterals spacing in excess of $0.65/2$.

Rizwanullah (1988) conducted various experiments to find the effect of water head and soil unit weight on infiltration characteristics and suggested that:

- i. Infiltration rate increases with increase in water head.
- ii. Infiltration rate decrease with increase in soil unit weight.

Aron- G. *et. al.* (1988) stated that Horton and SCS equation are frequently used in modeling infiltration rate and time, whereas the SCS equation suffers from the complete lack of a time relationship. The Horton equation was modified to make the infiltration rate a function of cumulative antecedent infiltration. A linear reservoir is proposed to delay the SCS infiltration increments.

Wolf (1988) formulated a three layered infiltration model using Green-Ampt approach. The characterization of the surface and tilled layers are

transient, being subjected to surface sealing and consolidation respectively. A relationship for the hydraulic conductivity of the tilled layer as a function of soil and applied rainfall characteristics was developed.

- (i) Wetting front in surface layer at time of ponding.

$$I_c = S_f M_1 (I.K_1^{-1} - 1) \quad 2.14$$

- (ii) Wetting front in the filled layer

$$I_c = M_2 K_2 (K_1 - I)^{-1} [I (L_1.K_1^{-1} - L_2.K_2^{-1})] S_f^2 + L_1 (M_1 - M_2) \quad 2.15$$

Where,

S_{f1}, S_{f2} = average saturation at the wetting front when it is the 1st and 2nd layer respectively.

M_1, M_2 = initial moisture deficit. In 1st and 2nd layer (V.V.) respectively.

K_1, K_2 = hydraulic conductivity in 1st and 2nd layer respectively.

I = application rate (depth/time)

L_1 = thickness of 1st layer

Kar, Amitah (1989) conducted the series of experiments in soil bins filled with sand loam soil, to find the effect of water head and soil unit weight on infiltration characteristics and suggested that:

- (i) Infiltration rate decreases with increase in time and becomes almost constant after 80 minutes.
- (ii) Infiltration rate (initial and constant both) is directly proportional to the water head on soil surface i.e. If increase with the increase in water head.
- (iii) Infiltration rate (Initial and constant both) is inversely proportional to the soil density.

- (iv) Accumulated infiltration is high for the soils of low density and low for soils of high density. Accumulated infiltration is high for higher water head and low for low water heads.

This means that the accumulated infiltration is directly proportional to the surface water head and inversely proportional to soil density.

Sunny Bindu S. and Padmalaya, T. (1989) conducted a series of experiments to find the effect of water head and soil unit weight on infiltration characteristics and suggested that:

- (i) The rate of infiltration has been found to be directly proportionate to the surface water head equation.
- (ii) Infiltration rate is found to be inversely proportional to soil unit weight.
- (iii) Infiltration rate becomes almost constant after 85th minutes.

Baker, R.S. and Hillel Daniel (1990) predicated that occurrence of finger ring and the fractional wetted volume during infiltration into layered soil in terms of measurable hydraulic property. When the conductivity of a coarse textured sub-layer as its effective water entry suction, is greater than the rate of transmission through a fine-textured top layer, the flow velocity increased across the inner layer plane.

Jaynes, D.B. (1990) measured I_r and soil temperature during a five days period in a 6.1 m file plot ponded with approximately 40 minute of water. He observed that I_r varied during a 24 hrs period with a maximum at approximately 17:00 hours and a minimum about 07:00 hours very day. The water viscosity in response to diurnal temperature change causes I_r to vary throughout the day.

Keller and Blisener (1990) considered the interest rates (r_i), the expected life of investment t , and an estimate of the expected annual rate of escalation in energy cost. The present worth of the escalating energy factor and the equivalent annualized cost of escalating energy factor was computed by the following equations:

$$PW(e) = \frac{[(1+e)^t - (1+r_i)^t] [r_i]}{[1+e] - (1+r_i) [(1+r_i)^t]} \quad 2.16$$

and equivalent annualized cost of escalating energy factor at annual rate of energy escalation, EAE (e) is calculated as:

$$EAE(e) = \frac{[(1+e)^t - (1+r_i)^t] [r_i]}{[1+e] - (1+r_i) [(1+r_i)^t]} \quad 2.17$$

The standard capital recovery factor, CRF is computed by

$$CRF = \frac{[R_i (1+r_i)^t]}{[(1+r_i)^t - 1]} \quad 2.18$$

Where,

- E = decimal equivalent annual rate of energy escalation
- r_i = decimal equivalent annual interest rate
- t = number of years in the life cycle.

The total annual cost was calculated as

- (i) Annual fixed cost, F.C. is calculated by

$$F.C. = CFR \times IC \quad 2.19$$

Where,

IC = initial cost of pipe

- (ii) The annual operating cost, O.C. is computed by the following relations

$$O.C. = 0.735 \times ah \times EAE (e) \times Cpl \times th. \quad 2.20$$

Where,

P = power in KWH

H = frictional head loss between two successive nodes (m)

Q = discharge (l/s)

Cpl = cost of fuel per KWH

th = number of working hours

- (iii) The total annual cost, Tc is the sum of the annual fixed and operating costs
i.e.

$$Tc = Fc + O.C. \quad 2.21$$

Reynold, W.D. and Erick, D.E. (1990) studied the ponded infiltration from single ring considering soil hydraulic properties, ring radius, depth of ring insertion and depth of ponding into account.

Smith R.E. (1990) found that most soils in nature exhibit same degree of layering, while infiltration theory is largely confined to homogenous profiles. He studies a two layered soil profile and stated that for Ic the behaviour of two

layers of the infiltrating system can be characterized by the two infiltration parameter K_s (hydraulic conductivity at natural field saturation) and G (parameter in combination of initial soil water deficits and capillary drive).

Starr, J.L. (1990) observed that infiltration of water into soil is controlled by complex set of soil and biotic factors and may be an important factor affecting the fate of water and agro-chemicals under different tillage systems. He studied the spatial and temporal variation of ponded infiltration.

Pelegrin- F; Moreno – F. (1993) studied the effect of variation tillage systems on the water infiltration in a sandy clay loam soil (Calcic haploxeralf) from Seville, Province was studied. The following tillage methods were considered. Mould board ploughing (MP), Cultivator application © and no tillage (NT). In each treatment, water infiltration was measured using both double ring infiltrometer and rainfall simulator. Infiltration rates for MP and C treatment were significantly ($P = 0.05$ level) higher than for NT treatment. The infiltration rates in the plough pan of the MP and C treatment were not significantly different ($P = 0.05$ level) to those of the consolidated zone (20 cm depth) in the NT treatment. For the different soil conditions created with the tillage methods used.

Hathoot *et. al.* (1994) presented a new design technique for sprinkler irrigation laterals with equally spaced sprinklers and constant longitudinal slope. The technique uses the Darcy-Weisbach friction formula and account for the variation of the friction coefficient for a significant practical portion on a Moody diagram. The head loss in sprinkler risers as well as losses in lateral pipefitting is considered. A computer program employing this technique was developed so as to provide sprinkler outflows and pressure head distributions along the lateral pipe.

Unger and Jones (1994) studied the effect of tillage induced aggregates on infiltration rates differed due to tillage aggregate size, and interaction effects, but the maximum differences was only 8.1 mm/ha Suggesting that difference

in filtration rate have little significant during short intense rain storm in under semiarid condition. Cumulative infiltration appears to be of greater significance, it was greatest for large aggregates. The ploughing and dishing treatment gave the most large aggregate under field conditions, ploughing and dishing treatment and sweep treatments had similar cumulative infiltration rates, however, tillage under cut the surface and retained more residues in the sweep treatment. Thus neglecting the advantage of larger, but apparently less stable aggregates.

Paramasivam (1995) studied five typical soil profiles under lower Bhavani Project Command Area, Tamil Nadu, representing various physiographic situations were studied. Soil texture, pH, Electrical conductivity and organic carbon content etc. were influenced by physiographic units. The infiltration rate and hydraulic conductivity were high in the lithic Haplustalf and Low in the typic Haplustalf and typic chromustert (black clay loam soil). Moisture retention at variation tensions indicated that upper terrace to middle terrace soils (Oithic Haplustalf, typic ustochrept, typic ustifluvenn, Typic Haplustalf) have low available water content compared to physiographically lower typic chromustert.

Painuli and Pagliai (1996) stated that modifications to the porosity of clay, loam and sand soil by studied on undisturbed soil columns (diameter 5.5 cm and length 25 cm). Porosity (>30fm), pore shape, size distribution and pore length were measured on thin sections by image analyzing computer. The area occupied by pores, their numbers of length f elongated pore decreased with the increased level of water infiltration. Modifications in pore size distribution also occurred. These changes were relatively rapid with initial quantities of changes were maximum in clay and minimum in sand.

Faoround *et. al.* (1996) studied a volume balanced technique utilizing irrigation advance and recession functions, numerical integration and an optimization procedure was developed to determine infiltration parameters.

The procedure is simple yet rational and accounts for spatial variability of soil characteristics. The required data were flow rate, the coefficient and exponents of the advance and recessions functions and inflows shut at time. In a field experiment on a clay loam soil in Alberta, Canada, infiltration rate estimated by this technique were similar and in close agreement with those measured with a ring infiltration. Except for two border strips: There were no significant mean differences between simulated (I_s) and measured (I_m) infiltration rates. In the two non-conforming border strips, field measured infiltration rates were higher than those simulated with the volume balance approach due mainly to spatial variability of soil characteristics and partly to lateral flow which occasionally occurs when measuring infiltration with a ring infiltrometer.

Unger (1996) studied that adverse soil physical conditions that limit soil water infiltration, root development, and crop yield could develop when using a non-tillage system, especially in humid regions or for irrigated crops. This study determined the effects of tillage treatments and controlled traffic on soil bulk density, penetration resistance, hydraulic conductivity, water content and organic matter concentration. Treatments were no tillage with residues left standing or shredded and no tillage after wheat and conventional tillage after sorghum (NT-CT). Determinations were made at traffic furrow, non-traffic furrow and row positions, after grain sorghum (*sorghum bicolor*) harvest in 1992. the grain sorghum had been grown in rotation with winter wheat. (*Triticum aestivum*) under limited irrigation conditions on a clay loam (Torrtic Paleustoll) in Texas, U.S.A. from 1986 to 1992. Tillage treatment did not significantly ($P = 0.05$) affect any determined variable. Mean penetration resistance was greatest (1.23 Mpa) in the traffic furrow but sampling position did not affect bulk density. Differences in hydraulic conductivity were significant ($P = 0.05$) only due to sampling depth, but tended to be greater in row than in furrow positions and with the NT-CT treatment than with other treatments. These results show that adverse, soil physical condition (Increased

bulk density and penetration resistance) development is limited to designated traffic zones, when using no tillage for irrigated crop production.

Wu-L, *et. al.* (1997) developed an axis symmetric 3-dimension numerical model was used to simulate water infiltration in single and double ring infiltration, as well as one dimensional (1-dimension)infiltration for three well studied soil types (a fine sand, a light clay and sandy clay loam) separating different textures and hydraulic properties. The infiltration rates of a single ring infiltration were 'f' times greater that the 1-dimension infiltration, where 'f' was a correction factor dependent on soil initial and boundary conditions and ring geometry. When the configuration of a typical double ring infiltration was used in simulation (inner and outer rings were 20 cm and 30 cm in diameter respectively). The simulated infiltration rates were W80% of the single ring rates. When the outer ring diameter was increased to 120 cm (inner ring kept at 20 cm). The double ring method measured infiltration rate were 120-133% of the 1-dimension infiltration rates for the three test soils. Compared with the constant head method, falling head infiltration rate dropped as much as 30% as the ponded head dropped from the 5 to 1 cm in the sandy clay loam. Layered soil can significantly affect infiltration rates, depending on the position of the wetting front relative to the textural discontinuity and the time measurement. Time at which the layering effects infiltration can be estimated from and the cumulative infiltration.

CHAPTER – III

MATERIALS AND METHODS

MATERIAL AND METHODS

This chapter deals with the methodology adopted for the study of comparative evaluation and economic selection of lateral for abbreviated sprinkler and micro sprinkler irrigation system for clay loam soil. It describes the methodology adopted for the development of computer software for computation of over lapped pattern and determination of uniformity coefficient. It explains the evaluation of abbreviated overhead sprinkler and micro sprinkler uniformity. It describes the methodology adopted for determination of irrigation period for various crops at different sprinkler and micro sprinkler spacing and also the comparative study of selection of economical pipe size for overhead sprinkler and micro sprinkler for clay loam soil.

3.1 Experimental Site

The experimental site was located at crop research farm at Allahabad Agricultural Institute-Deemed University.

3.2 Equipment and Materials

Over head sprinkler components manufactured by Hasti and Micro sprinkler components manufactured by Rain Bird were used for the experiment. The complete experimental set consisted of the following equipment and accessories.

3.2.1. Pump

The water source used for this experiment was a submersible pump installed at the crop research farm. The pump had the following specification:

No. 3964821

Type: K.K. Submersible pump

H.P. = 10 H.P.

Head – 56 m

Speed – 2900 rpm

Discharge – 4800 l/hr

3.2.2. Lateral Line

A 132 m long lateral line having a diameter of 75 mm was attached to the main line on which the sprinkler set assembly was attached. In the case of micro sprinkler, the 16 mm PVC lateral was attached to the sprinkler rise. In both the case a pressure gauge was attached on the sprinkler/micro sprinkler rise.

3.2.3 Sprinkler head

For conducting the experiment, two sprinkler head made of brass and micro sprinkler head made of plastic were used. Specifications of these sprinkler and micro sprinkle heads are given in table 3.1. The riser height in the case of overhead sprinkler was 1.00m and for micro sprinkler it was 30 cm.

Table 3.1: Specification of the sprinkler and micro sprinkler head models.

Model	Angle θ	Nozzle diameter		Discharge l/Sec					
		Ranger (mm)	Spreader (mm)	1.0 kg/cm ²	1.5 kg/cm ²	2.0 kg/cm ²	2.5 kg/cm ²	3.0 kg/cm ²	3.5 kg/cm ²
LPG	27°	5.1	3.1	--	--	0.363	0.427	0.556	0.640
K24	27°	5.1	--	--	--	0.313	0.353	0.380	0.447
LPG	27°	0.25	--	0.0096	0.0113	0.015	--	--	--
K28		cm							
Rain spray									

3.2.4. Miscellaneous

A pressure gauge having a range of 0.5 kg/cm² to 5.0 kg/cm² was used to measure the pressure on the main line. Whereas a pressure gauge was also fitted near the sprinkler/micro sprinkler nozzle. Catch cans were used to collect the precipitation from the sprinklers and micro sprinklers. The height

and diameter of catch cans were 70 mm and 40.2 mm respectively as per the recommendation given IS: 12232 (part 2 1987, section-2). The catch can spacing for the overhead sprinkles were maintained at 1m and for micro sprinkler at 0.50 cm.

The catch cans used for collection the discharge from the micro sprinkler were cylindrical from the top to bottom. The open edges were sharp and free from deformation. The collections were such that none of the water collected was splashed out. The height of the collector was at least twice the depth of water collected during the test. Soil auger was used to extract the moist soil from different depths. The moist and dry soil was weighed with the help of a digital balance and dried in the oven.

3.3 Determination of field capacity

Field capacity was determined to obtain the water holding capacity of the soil. A square bund of 1 mx1m having a height of 10cm was made in the center of the field. A head of 10 cm was maintained for 36 hrs after which it was observed that infiltration was almost negligible. After 72hrs. the moisture content at a depth of 0cm, 10cm, 20cm, and 30cm and determined and given in Appendix – A2.

3.4 Determination of bulk density:

Bulk density was also determined before the experiment. The bulk density was determined by cylinder method using oven drying method. The bulk density was determined at 0cm, 10cm, 20cm and 30 cm and given in Appendix-A3.

3.5 Experimental layout:

All the connections on the main line and lateral line were checked properly to ensure that no leakage of water was taking place.

Collection of catch can data was done on a cemented floor as well as on soil surface. The collection of catch can data on the cemented floor for single nozzle and double nozzle over head sprinkler were done at four operating pressures at 2.0 kg/cm², 2.5 kg/cm²/3.0kg/cm² and 3.5 kg/cm² respectively, and 1.0kg/cm², 1.5kg/cm² and 2.0 kg/cm² for micro sprinkler. The catch can data was collected for a quarter of wetted sprinkled area as single leg catch can data. The catch cans were placed in two dimensional array at 1 m apart for overhead sprinkler and at 0.5m for micro sprinkler. The catch can data was measured after each irrigation period which was of one hour duration and given in Appendix A4 (1-11). In order to determine the depth of moisture in the soil, it was determined that only a strip of 30° soil making an internal angle of 30° will be wetted to determine the depth of average moisture content at 0, 10, 20 and 30 cm for single nozzle and double nozzle over head sprinkler at the pressures mentioned above and given in Appendix A5 (1-11). This was done to develop a regression model between the depth of water in the soil resulting from sprinkled water from the sprinkler under unsaturated infiltration conditions.

3.6 Computation of overlapped catch can data

Overlapped catch can data was obtained by converting the single leg catch can data into full circle. There after overlapping for over head sprinklers and microsprinklers was done considering the distance between the sprinkler and lateral to be 3 m x 5m, 6, x 10m, 8m x 10m, 9m x 12m, 12m x 15m, 15m x 18m, 18m x 20m, 21m x 20m and 2m x 2m, 3m x 3m, 4m x 4m, 5m x 5m and 6m x 6m respectively. The overlapping was done for single nozzle, and double nozzle overhead sprinkler at an operating pressure of 2.0 kg/cm², 2.5 kg/cm², 3.0 kg/cm² and 3.5 kg/cm² respectively and at 1.0 kg/cm², 1.5 kg/cm² and 2 kg/cm² respectively for micro sprinkler. Those spacings at which the depth of over lapped water at any point in the over lapped area is zero, was not considered.

3.7 Determination of Uniformity Coefficient.

The overlapped pattern from a single sprinkler head is obtained for desired spacing as mentioned in section 3.6. The software for calculating uniformity coefficient of the overlapped pattern for different spacing is included in the computer programme and given in Appendix A6. The following equation developed by Christiansen, (1941) was used in the software to calculate the uniformity coefficient and given in Appendix A7 (1-11)

$$UCC = 100 (1 - (\sum x/m \times d.no.) \dots\dots\dots 3.1$$

Where,

UCC = Christiansen Uniformity coefficient (%)

X = [Z - m] absolute deviation of the individual observation from the mean (cm)

m.d = ($\sum x$)/no = mean depth of observation (cm)

n. = number of observation.

3.8 Determination soil moisture content.

To determine the amount of water infiltrated all along the experimental strip, the moisture content was obtained at distance of 1m apart as per the distribution of catch cans. The moisture was obtained at a depth of 0, 10, 20 and 30cm. Digital balance was used to measure the wet weight and dry weight of the soil samples. Determination of moisture content was done by gravimetric method. After the determination of moisture content at different depths average moisture content was obtained. Later on, the moisture content obtained in percentage was changed into depth of water in mm using the following relationship and given in Appendix A5 (1-11)

$$\theta_v = \frac{\theta_m > b}{>w} \quad 3.2$$

$$\theta_d = \theta_v \times d \quad 3.3$$

Where

θ_v = Volumetric moisture content as ratio

θ_m = moisture content either as a ratio or percentage

$>b$ = bulk density of soil gm/cm³

$>w$ = bulk density of water gm/cm²

θ_d = depth of water mm/d

d = depth of water

3.9 Development of computer software.

A software for computing UCC, UCC_{abb}, UCC_{sm}, mean depth (full scale and abbreviated), mean depth of moisture and total annual cost per unit sprinkled area was developed according to Hart (1963), which calculates the Christiansen uniformity coefficient by converting a two dimensional rectangular array, by inserting necessary zeroes in the corners. This two dimensional array of single leg catch can data is converted into a single array and the software accepts these observations of catch can data from a single sprinkler and overlaps them to generate rectangular patterns for the desired spacing. The software was so developed that it could handle multiple sprinkler tests. The programme further calculates the abbreviation uniformity coefficient by selecting the first overlapped catch can data along the mainline for the desired spacing. The abbreviated uniformity coefficient is also calculated using the Christiansen uniformity coefficient method (1942).

After calculating the Christianen uniformity coefficient for the rectangular overlapped pattern the programme accepts the depths of overlapped precipitated water and incorporates it into the best fit curve equation to determine the overlapped soil moisture depth uniformity. This soil

moisture depth uniformity explains the areal distribution of overlapped precipitation and its distribution as soil water up to a depth of 30 cm. The computer software developed is given in appendix-A6.

3.10 Computation of overlapped soil water data.

The relationship between catch can data and the depth of moisture in the soil was found by the best-fit curve. The overlapped catch can data obtained and mentioned above was incorporated in the regression equation developed between depth of water in the catch can and soil moisture depth. The overlapped soil moisture depth was determined for 3m x 5m, 6m x 10m, 8m x 10m, 9m x 12 m, 12m x 12 m, 18m x 20m and 20m x 21m and at 2m x 2m, 3m x 3m, 4m x 4m, 5m x 5m and 6m x 6m respectively for overhead sprinkler as well as micro sprinkler and is given in Appendix A7 (1-11).

3.11 Evaluation of abbreviated overhead sprinkler and micro sprinkler uniformity coefficient.

Uniformity and depth of application can be estimated using all the cans on a grid layout as recommended in ASAE standards 5330 and 5398T or using a subset thereof. The challenge is to find a subset representative of the complete set, without sacrificing accuracy and hence abbreviate the evaluation procedure (section 3.9) and given in appendix A7 (1-11)

3.12 Determination of duration of irrigation.

The total depth of irrigation required is the product of rooting depth (m), plant available water (mm/m) and readily available soil water (fraction). The duration of irrigation will depend upon the spacing between the sprinklers and the laterals and the soil characteristics of clay loam soil as given in Appendix A8.

3.13 Cost Analysis of sprinkler lateral.

The total annual cost per unit overlapped sprinkled area at different spacings and operating pressures was calculated. The cost of the components of sprinkler lateral is given in Appendix A9. The procedure for the cost analysis is given in the following step.

Step 1:

The head loss due to friction was calculated by using the Hazen William equation as:

$$hf1 = \frac{F.K. (ns.q/c)^{1.85} ns.\delta l}{di^{4.87} \times 100} \quad 3.4$$

Where

Hf1 = head loss due to friction in lateral pipe (m)

k = a constant (1.212×10^{12})

F = multiple outlet factor which was taken as 0.38

(Wu and gitlin, 1983) G

δl = sprinkler spacing along the lateral (m)

q = discharge of a sprinkler head (l/sec)

ns = no. of sprinklers on a lateral line

di = inner diameter of lateral pipe (mm)

c = friction coefficient (120)

Step 2:

The head loss due to friction and head gain or loss due to elevation differences was kept within 20% of the average operating pressure head. For this equation 3.3 was written in terms of lateral line and the slope along the lateral line was added as follows:

$$\frac{F.K. (ns. q/c)^{1.85} . ns. \delta l}{di^{4.87} \times 100} + \frac{\delta l \times ns.S}{100} = 0.2ha \quad 3.5$$

Where

ns = number of sprinklers

ha = total head at sprinkler inlet (m)

q = discharge (L/S)

S = slope %

The value of S will not affect the lateral length because the slope is considered as zero and the length of the lateral line would not increase in a complete sprinkler spacing due to small gain in head if any along the lateral line. Therefore neglecting the slope along the lateral line the above equation was written in the following form to calculate the value of ns:

$$\frac{F.K. (ns. q/c)^{1.85} \times ns \times \delta l}{d_i^{4.87} \times 100} = 0.2ha \quad 3.6$$

or

$$ns = \left[\frac{0.2ha \times d_i^{4.87} \times 100^{1/2.852}}{F.K. (q/c)^{1.85} \delta l} \right] \quad 3.7$$

By using the equation 3.7 the total number of sprinkler on a lateral line was calculated:

Step 3:

The inlet pressure head at the lateral was found as follows:

$$h_i = h_a + \frac{3}{4} h_{f1} + h_r \quad 3.8$$

Where

h_i = initial pressure head (m)

h_r = sprinkler riser height which was taken as 1.0 m

Step 4:

The annual fixed cost of the lateral line was calculated by the following equation (Keller and Blisner, 1990)

$$F_c = (c_p + c_s + C_r + c_c) \text{ C.R.F.} \quad 3.9$$

Where

F_c = annual fixed cost of the lateral line with sprinkler heads, risers and couples

C_p = Initial cost of the pipe in the lateral line (Rs.)

C_s = Initial cost of sprinkler heads in the lateral line (Rs.)

C_r = Initial cost of sprinkler risers in the lateral line (Rs.)

C_c = Initial cost of sprinkler couplers in the lateral line (Rs.)

C.R.F = Capital recovery factor (Keller and Blisner, 1990)

Step 5:

The energy cost was calculated by the following equation

$$EC = (7.35 \text{ q/ns} \times h_i \times t \times c_e \times eae) \quad 75 \quad 3.10$$

Where

EC = annual energy cost of operating the lateral line (Rs.)

t = annual use per hours.

c_e = cost of electricity (Rs/KWh)

eae = equivalent annualized cost factor of escalating energy taking into account the time value of money over the life cycle (Kdler and Bliesner, 1990)

Step 6:

After calculating the annual fixed and energy cost of the lateral line, the total annual cost of lateral, per unit sprinkled area was finally calculated:

$$T_c = \frac{F_c \times EC}{L \times \delta m} \quad 3.11$$

Where

T_c = total annual cost of lateral per unit

Sprinkled area (Rs./m²)

L = total length of lateral line (m)

δm = spacing between laterals (m)

CHAPTER – IV

RESULTS AND DISCUSSION

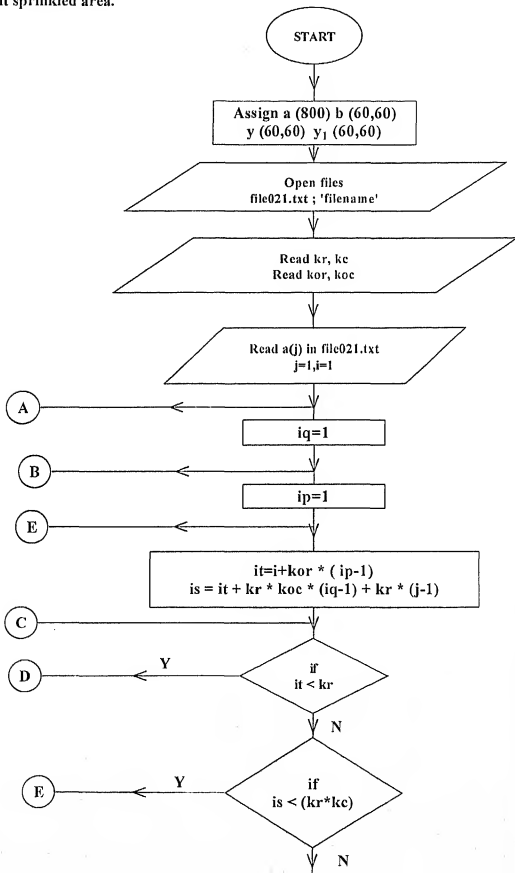
RESULTS AND DISCUSSION

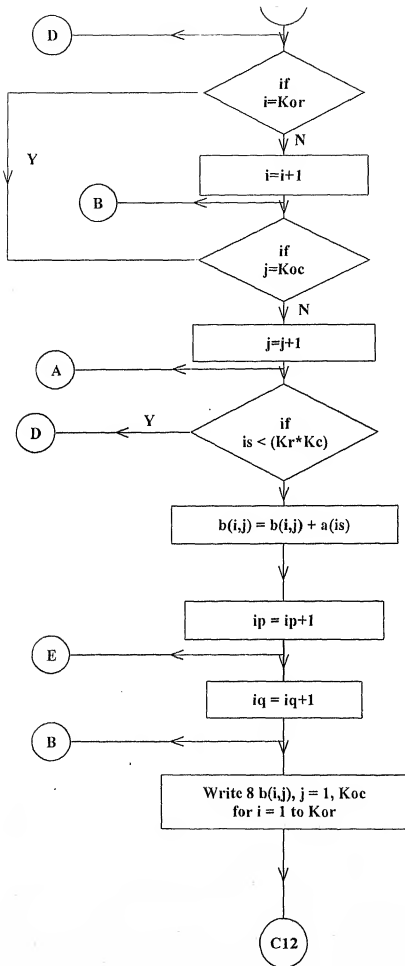
This chapter highlights the results obtained by the developed computer software for the computation of overlapped pattern and determination of Uniformity Coefficient (UCC). It explains the abbreviative uniformity coefficient (UCC_{abb}) of overhead sprinkler and microsprinkler in relation to full scale overlapped uniformity. This chapter includes the irrigation period required for the crops irrigated by overhead sprinkler and microsprinkler. A comparative evaluation and economical selection of sprinkler and microsprinkler lateral for different sprinkler lateral diameters at different sprinkler spacings and operating pressures is also included in this chapter.

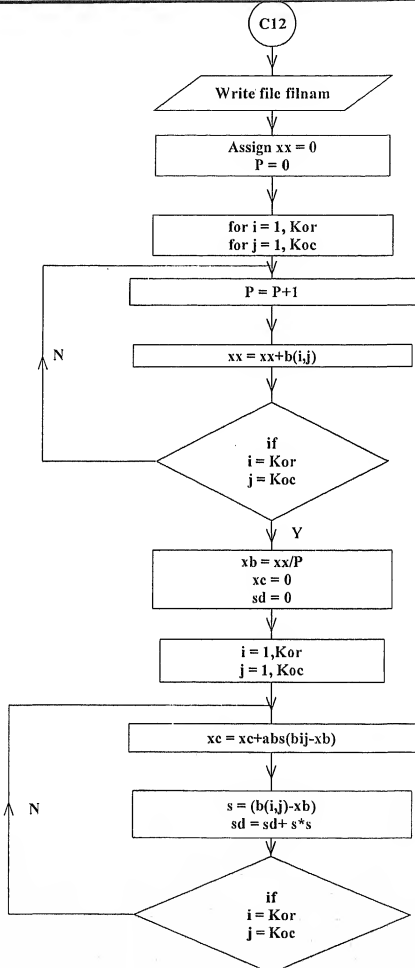
4.1 Computer software for computation of overlapped pattern and uniformity coefficient.

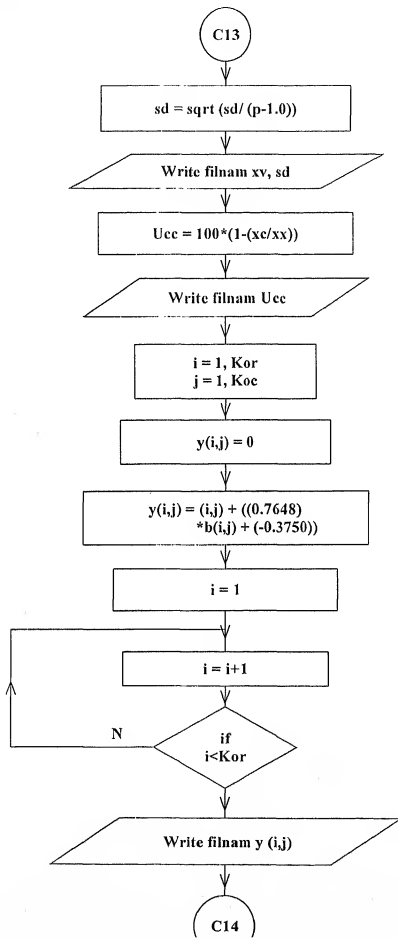
The computer software developed for the computation of overlapped pattern and UCC, computes the UCC for single nozzle and double nozzle overhead sprinklers at a given spacing of 3m x 5m, 6m x 10m, 8m x 10m, 9m x 12m, 12m x 15m, 15m x 18m, 18m x 20m and 20m x 21m respectively at an operating pressure of 2.0 kg/cm², 2.5 kg/cm², 3.0 kg/cm² and 3.5 kg/cm² respectively. It also computes the UCC for the microsprinkler operating at a pressure of 1.0 kg/cm², 1.5 kg/cm² and 2.0 kg/cm² respectively at a spacing of 2m x 2m, 3m x 3m, 4m x 4m, 5m x 5m, 6m x 6m respectively as given in Appendix – A7 (1-11). The program computes the UCC by converting the original number of rows and columns into the desired number of rows and columns. The program also calculates the mean depth of water obtained in the overlapped zone. The uniformity of soil moisture is determined by incorporating the overlapped depth of catchcan into the model obtained having the relation between the depth of water in the catch can and the resulting soil water depth at each respective pressure. Thus the depth of soil water is obtained. This depth of soil water is used by the program to calculate the soil moisture uniformity UCC_{sm} and given in Appendix A7 (1-11)

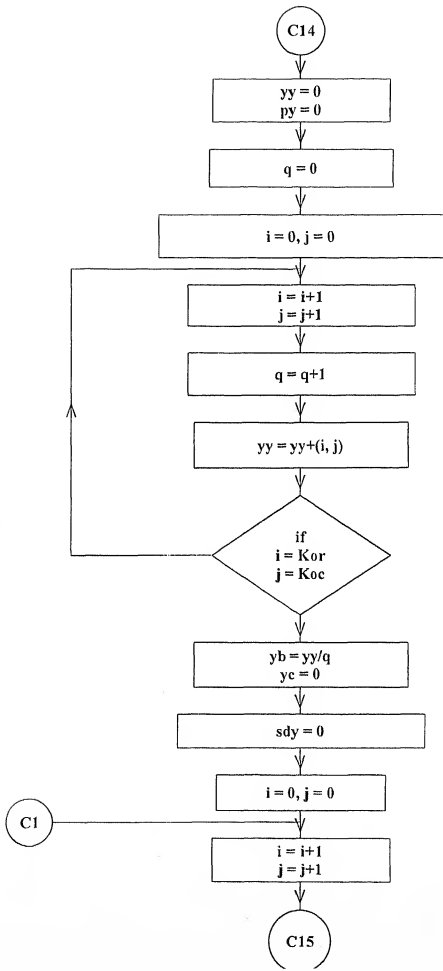
Fig. 4.1 Flow Diagram to calculate the UCC , UCC_{abb} , UCC_{sm} , overlapped mean depth of water in catchcan, overlapped abbreviated mean depth of soil moisture, number of sprinklers on lateral line, total length of lateral line and total annual cost for per unit sprinkled area.

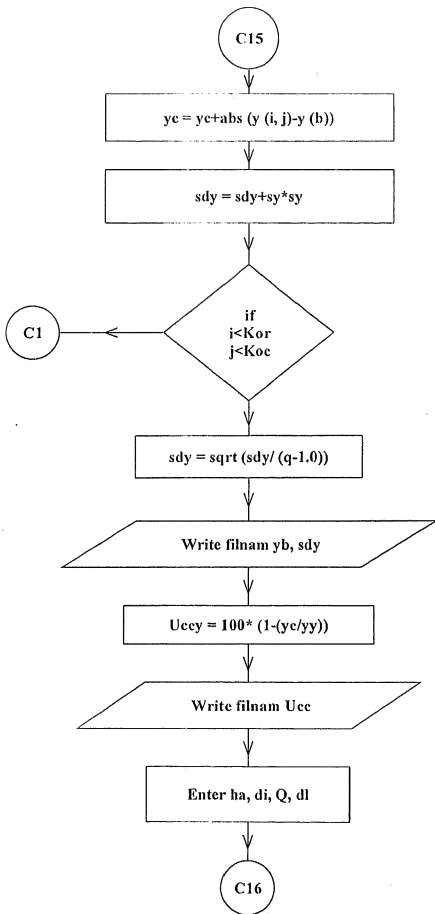












C16

Assign
 $f = 0.38$
 $k = 1.212 \text{ e}^{12}$
 $c = 120$

$r = (q/c)$

$ns1 = ((0.2 \text{ ha} * (di ** 4.87)) * 100)$
 $ns2 = ((f * k * (r ** 1.85)) * dl)$
 $ns = ((ns1/ns2) ** 0.3508)$

Write ns

$l = (ns * dl)$

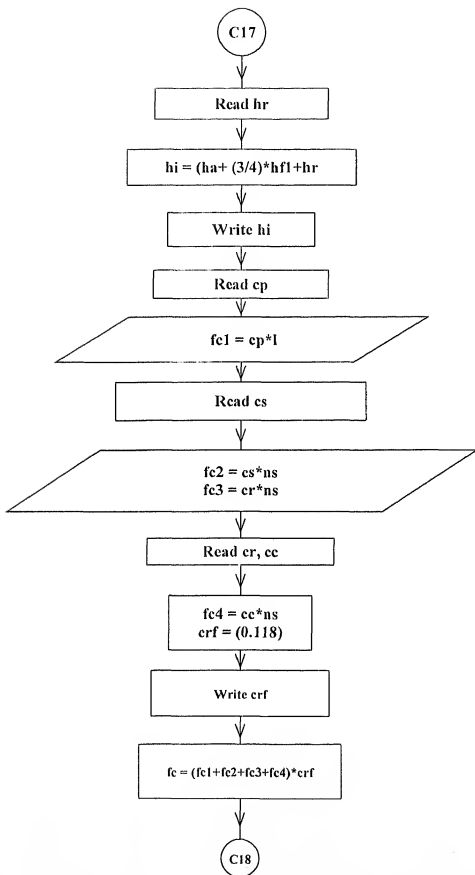
Write l

$hf11 = (f * k * ((ns * r) ** 1.85) * ns * dl)$
 $hf12 = ((di ** 4.87) * 100)$
 $hf1 = (hf11/hf12)$

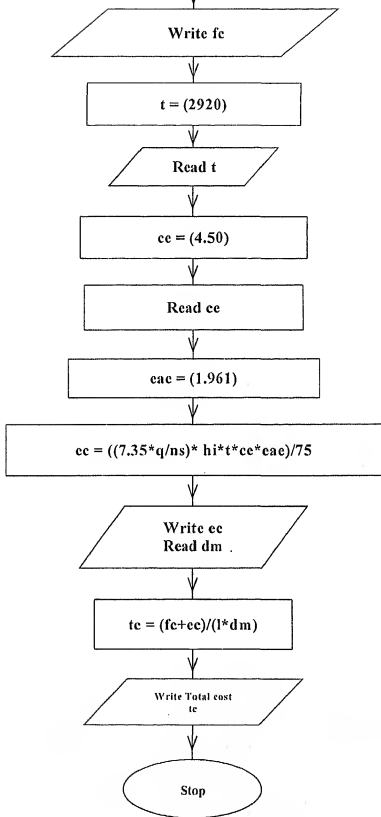
Write hr

$hi = (ha + (3/4) * hf1 + hr)$

C17



C18



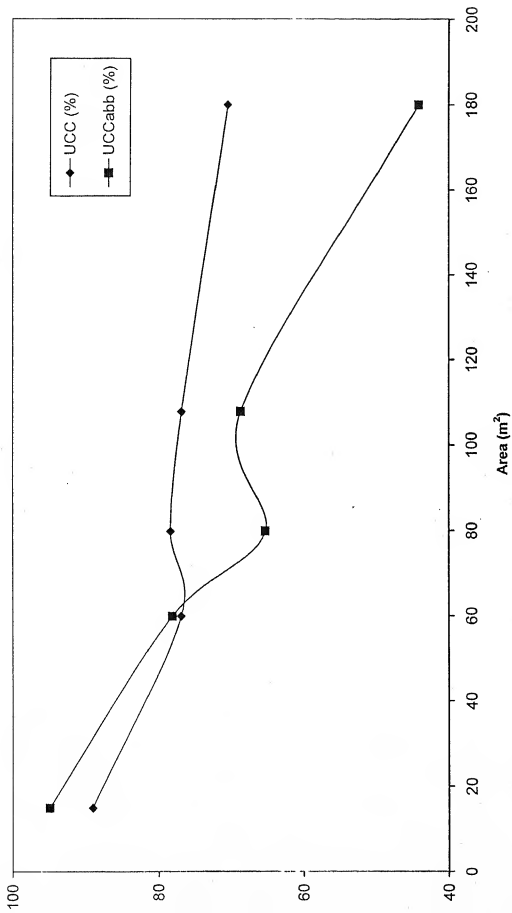


Fig. 4.2 Relationship between UCC (%), UCC_{abb} (%) and overlapped area (m²) for single nozzle overhead sprinkler at an operating pressure of 2.0 Kg/cm².

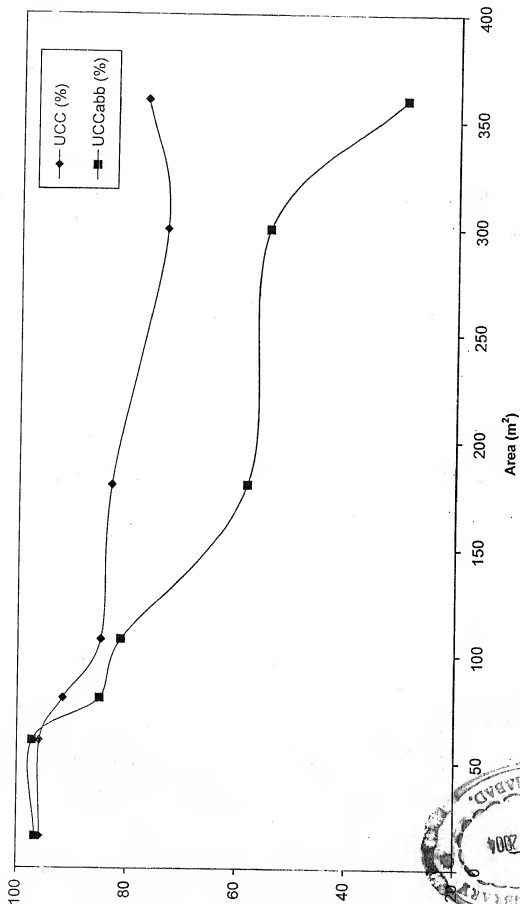
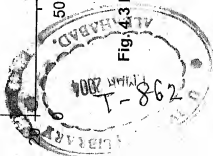


Fig. 4.3 Relationship between UCC (%), UCC_{abb} (%) and overlapped area (m²) for single nozzle overhead sprinkler at an operating pressure of 2.5 Kg/cm².

3774-20
5780.



The program further calculates the abbreviated overhead sprinkler and microsprinkler uniformity from the original overlapped catch can data. It only considers the first column of the original overlapped catch can depth and computes the mean depth and Abbreviated Uniformity Coefficient and given in Appendix A7 (1-11).

The software computes the total cost of the sprinkler lateral for a lateral diameter of 50mm, 75mm and 100mm for the permissible length of a lateral, taking into account 20 percent variation of the total pressure between the pipe inlet and at the end of the lateral and number of sprinklers on the lateral. The total annual cost is calculated for per unit of sprinkled area and is given in appendix A7 (1-11). The flow diagram of the program is shown in the figure 4.1.

4.2 Evaluation of abbreviated overhead sprinkler uniformity.

4.2.1 Single nozzle overhead sprinkler

The relationship obtained between the UCC and UCC_{abb} obtained for different operating pressures and spacings for single nozzle overhead sprinkler are discussed here.

From Fig 4.2, 4.3, 4.4, 4.5 it can be seen that at an operating pressure of 2.0 Kg/cm² the UCC_{abb} increases by 5.92% and 1.23% up to a spacing of 3m X 5m and 6m X 10m respectively. There after the UCC_{abb} reduces drastically by 13.05%, 8.16% and 26.33% at a spacing of 8m X 10m, 9m X 12m and 12m X 15m respectively. At an operating pressure of 2.5 Kg/cm² The UCC_{abb} increases by 0.88% and 1.36% for a spacing of 3m X 5m and 6m X 10m. Beyond the spacing of 6m X 10m the UCC_{abb} slightly reduces by 1.67%, 3.64%, for a spacing of 8m X 10m and 9m X 12m, thereafter it reduces drastically by 2.47%, 18.93% and 47.59% for spacing of 12m x 15m, 15m x 20m and 18m x 20m respectively.

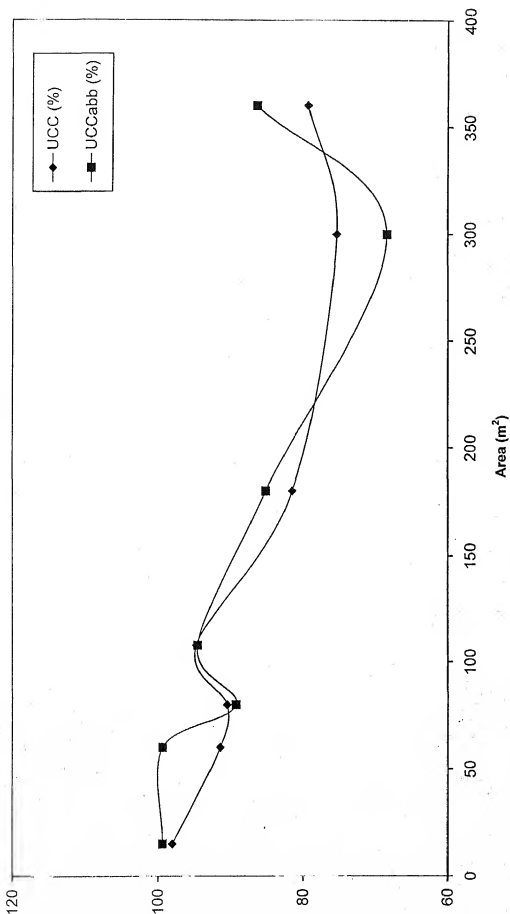


Fig. 4.4 Relationship between UCC (%), UCC_{abb} (%) and overlapped area (m²) for single nozzle overhead sprinkler at an operating pressure of 3.0 Kg/cm².

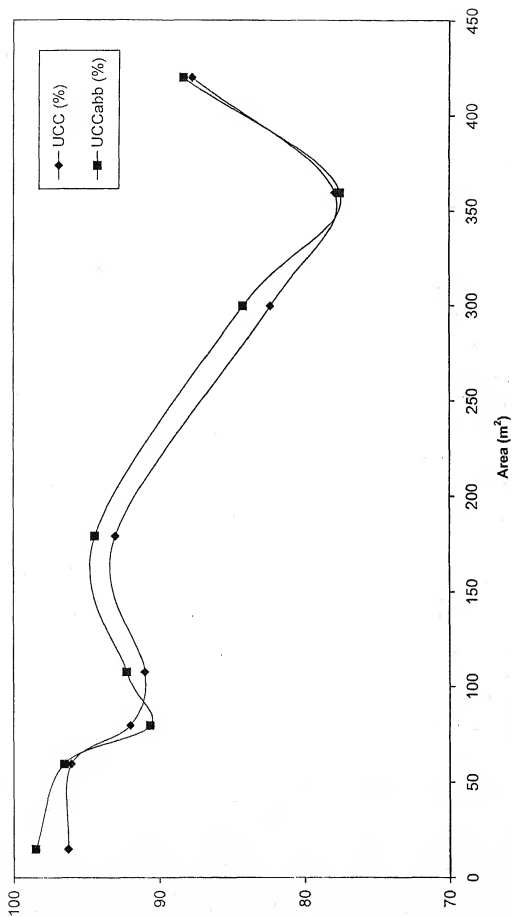


Fig. 4.5 Relationship between UCC (%), UCC_{abb} (%) and overlapped area (m²) for single nozzle overhead sprinkler at an operating pressure of 3.5 Kg/cm².

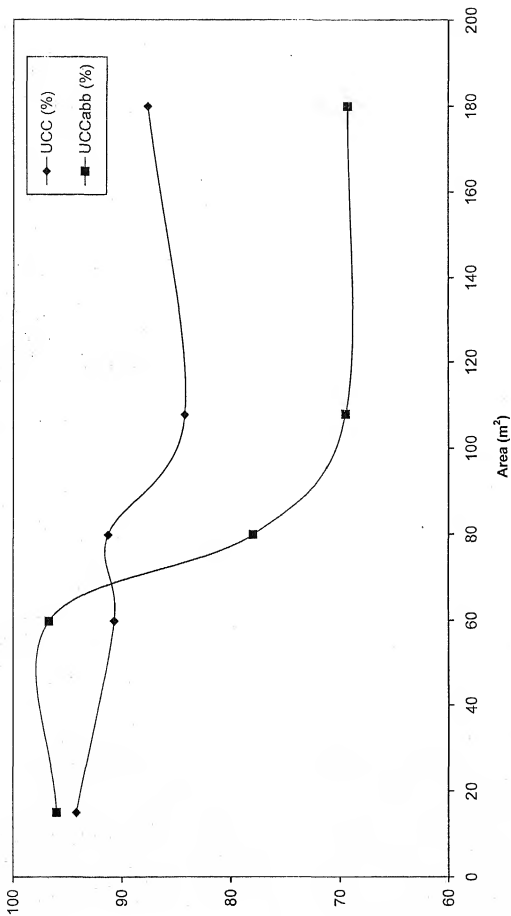


Fig. 4.6 Relationship between UCC (%), UCC_{abb} (%) and overlapped area (m^2) for double nozzle overhead sprinkler at an operating pressure of 2.0 Kg/cm².

At an operating pressure of 3.0 kg/cm^2 the UCC_{abb} increases by 1.38% and 7.98% for a spacing of $3\text{m} \times 5\text{m}$ and $6\text{m} \times 10\text{m}$, beyond that $8\text{m} \times 10\text{m}$ and $9\text{m} \times 12\text{m}$ the UCC_{abb} decreases by 1.24% and 0.21% respectively. At a spacing of $12\text{m} \times 15\text{m}$ the UCC_{abb} again increases by 3.67%. It further reduces to 6.99% at $15\text{m} \times 20\text{m}$ spacing and again increases by 7.01%.

At an operating pressure of 3.5 kg/cm^2 the variation in UCC_{abb} with respect to the UCC for all spacing is almost same. The UCC_{abb} is higher than the UCC by 2.14%, 0.50%, 1.37%, 1.40%, 1.90% and 0.63% for a spacing of $3\text{m} \times 5\text{m}$, $6\text{m} \times 10\text{m}$, $9\text{m} \times 12\text{m}$, $12\text{m} \times 15\text{m}$, $15\text{m} \times 20\text{m}$ and $21\text{m} \times 20\text{m}$ respectively. Whereas it is lower by 1.34% and 0.35% for a spacing of $8\text{m} \times 10\text{m}$ and $18\text{m} \times 20\text{m}$ respectively.

4.2.2 Double nozzle over head sprinkler

The relationship obtained between the UCC and UCC_{abb} obtained for different operating pressure and spacing for double nozzle overhead sprinkler are discussed here. From figure 4.6, 4.7, 4.8 and 4.9 it can be seen that at an operating pressure of 2.0 kg/cm^2 the UCC_{abb} is higher by 1.81% and 5.97% for a spacing of $3\text{m} \times 5\text{m}$ and $6\text{m} \times 10\text{m}$. Beyond a spacing of $6\text{m} \times 10\text{m}$ it reduces drastically by 13.29%, 14.78% and 18.42% for a spacing of $8\text{m} \times 10\text{m}$, $9\text{m} \times 12\text{m}$ and $12\text{m} \times 15\text{m}$ respectively.

At an operating pressure of 2.5 kg/cm^2 the value of UCC_{abb} when compared with the UCC is observed to follow the same trend as for 2.0 kg/cm^2 .

At an operating pressure of 3.0 kg/cm^2 the UCC_{abb} increases by 0.5% and 3.84% for $3\text{m} \times 5\text{m}$ and $6\text{m} \times 10\text{m}$ respectively. Thereafter it reduces by 7.44%, 3.42%, 12.64% and 19.29% for a spacing of $8\text{m} \times 10\text{m}$, $9\text{m} \times 12\text{m}$, $12\text{m} \times 15\text{m}$ and $15\text{m} \times 18\text{m}$ respectively. Thereafter it increases by 1.97% and 0.38% for a spacing of $18\text{m} \times 20\text{m}$ and $21\text{m} \times 20\text{m}$ respectively. At an operating pressure of 3.5 kg/cm^2 the UCC_{abb} increase by 0.20%, 5.83%, 2.06%, 0.76%, 0.66%, 0.22% and 1.0% for all spacings. At an operating pressure of 2.0 kg/cm^2 , 2.5 kg/cm^2 and 3.0 kg/cm^2 the value of UCC_{abb} follows the same trend as that of single nozzle overhead sprinkler where as for 3.5 kg/cm^2 its value are higher than UCC.

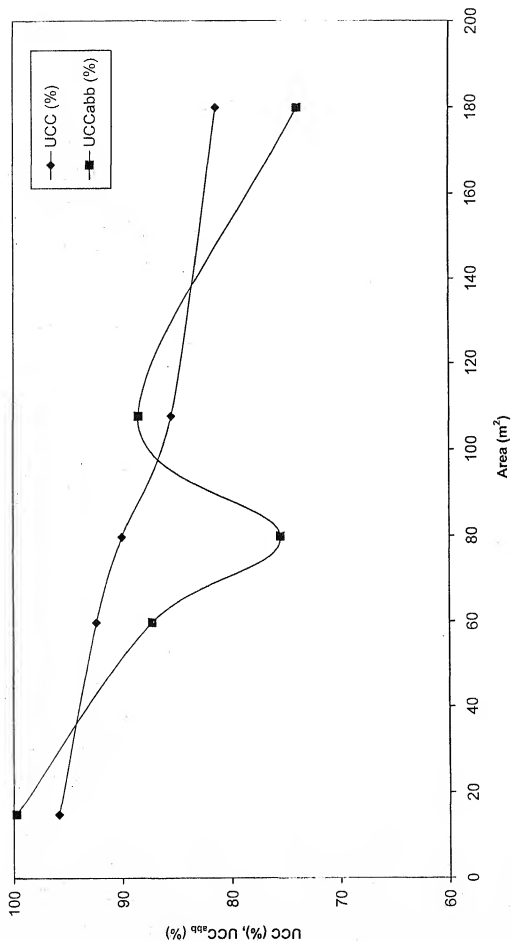


Fig. 4.7 Relationship between UCC (%), UCC_{abb} (%) and overlapped area (m²) for double nozzle overhead sprinkler at an operating pressure of 2.5 Kg/cm².

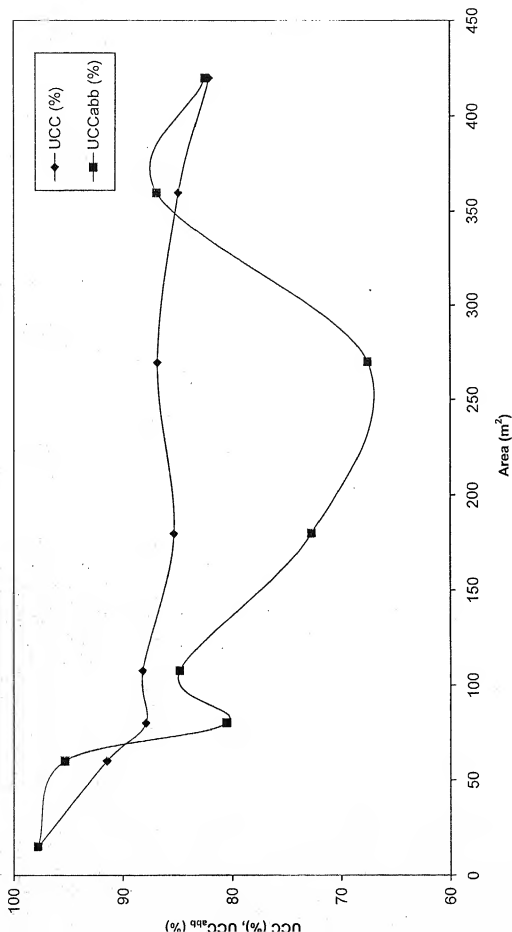


Fig. 4.8 Relationship between UCC (%), UCC_{abb} (%) and overlapped area (m²) for double nozzle overhead sprinkler at an operating pressure of 3.0 Kg/cm².

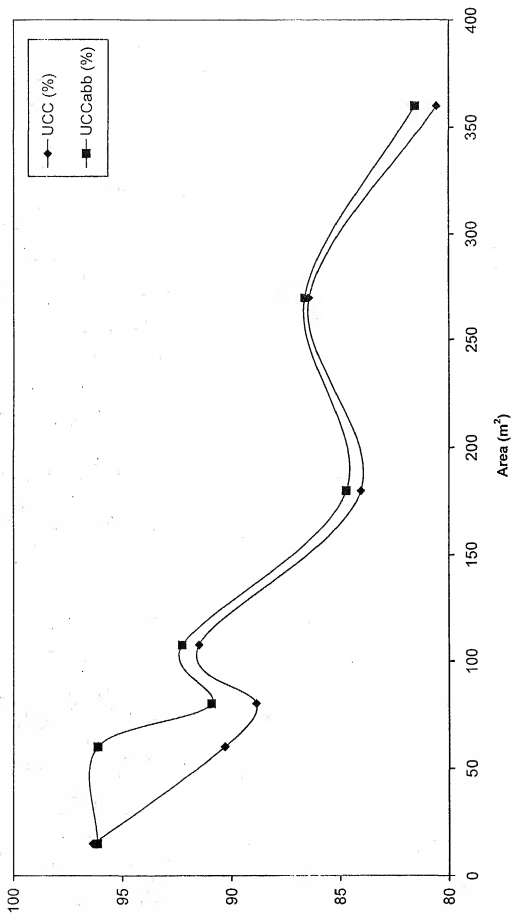


Fig. 4.9 Relationship between UCC (%), UCC_{abb} (%) and overlapped area (m²) for double nozzle overhead sprinkler at an operating pressure of 3.5 Kg/cm².

4.2.3 Microsprinkler

The relationship obtained between the UCC and UCC_{abb} for microsprinkler obtained for different operating pressure and spacings are discussed here. From figure 4.10, 4.11 and 4.12 it can be seen that at an operating pressure of 1.0 kg/cm^2 the UCC_{abb} is almost same as that of UCC at a spacing of $2\text{m} \times 2\text{m}$. At a spacing of $3\text{m} \times 3\text{m}$ the UCC_{abb} reduces by 4.49%. It reduces by 3.35% at a spacing of $4\text{m} \times 4\text{m}$. Beyond that at $5\text{m} \times 5\text{m}$ it reduces by 7.01% and at a spacing of $6\text{m} \times 6\text{m}$ it increase by 3.66% as compared with the UCC for the same spacing.

At an operating pressure of 1.5 kg/cm^2 it is seen that the UCC_{abb} when compared with the UCC at all spacing is found to be lower by 0.73%, 1.71%, 0.61%, 2.94% and 1.67% respectively. The same trend was followed when the microsprinkler was operated at an operating pressure of 2.0 kg/cm^2 . From figure 4.2, 4.3, 4.4 and 4.5 it can be seen that at lesser spacing the value of UCC_{abb} is always high for all the four sprinkler operating pressure whereas, as the spacing between the sprinkler and lateral increases the total number of depth of water in catch can increases, taking into account those catch cans which are at the periphery of the wetted circular area obtained by sprinkling the water from the sprinkler. Thus reducing the depth of water in the overlapped area. This fact can be seen from appendix A-4 (1-11) and A-7 (1-11)

As the operating pressure is gradually increased from 2.0 kg/cm^2 to 2.5 kg/cm^2 to 3.0 kg/cm^2 and 3.5 kg/cm^2 we can see from appendix A-4 (1-11) that the wetted area increases as the radius of throw (range) of the sprinkler increases. At 3.0 kg/cm^2 from figure 4.4 it can be sum that firstly the UCC_{abb} increases, then decreases, again increases, further reduces and finally increases drastically. This shows the large variation in the distribution pattern of depth of water in the catch cans. At a pressure of 3.5 kg/cm^2 the variation in the UCC_{abb} with respect to the UCC is very low because at a high pressure

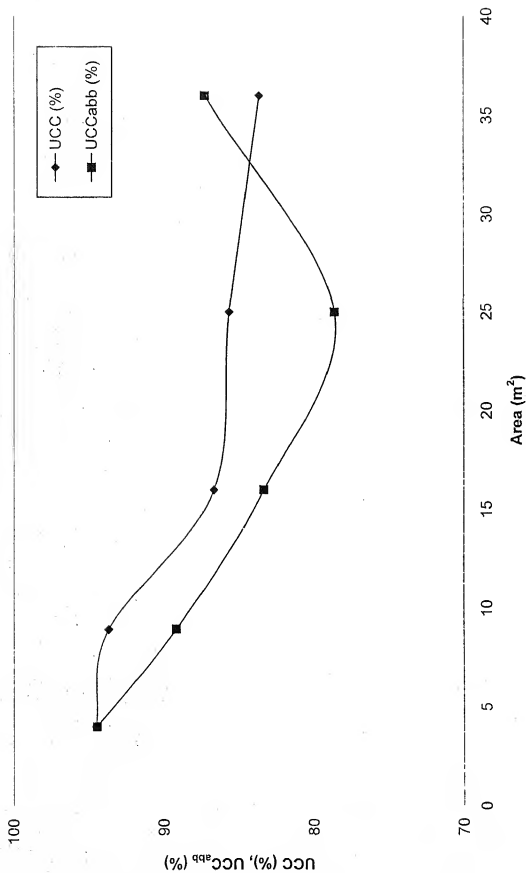


Fig. 4.10 Relationship between UCC (%), UCC_{abb} (%) and overlapped area (m²) for microsprinkler at an operating pressure of 1 Kg/cm².

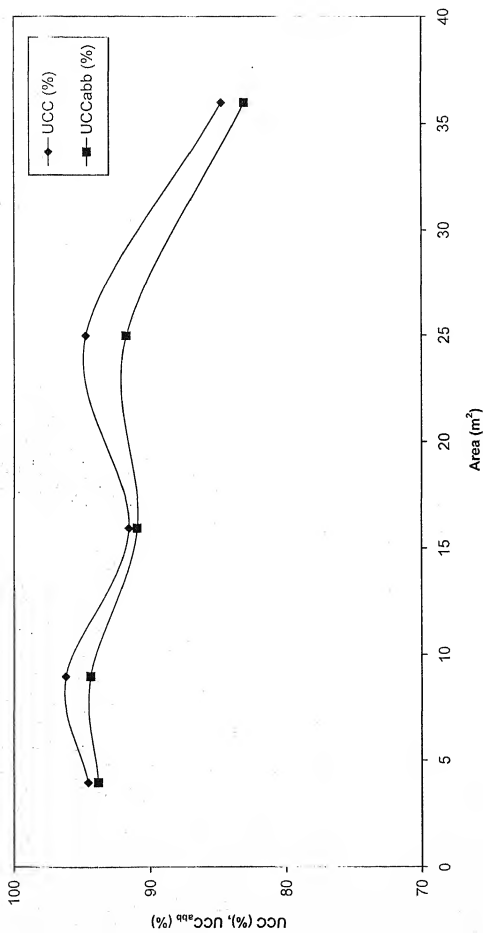


Fig. 4.11 Relationship between UCC (%), UCC_{abb} (%) and overlapped area (m²) for microsprinkler at an operating pressure of 1.5Kg/cm².

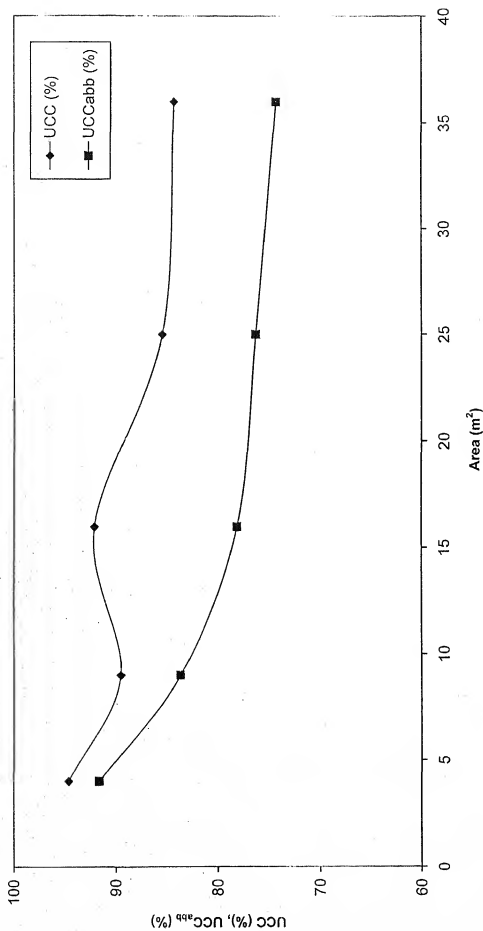


Fig. 4.12 Relationship between UCC (%), UCC_{abb} (%) and overlapped area (m²) for microsprinkler at an operating pressure of 2.0 Kg/cm².

the size of the droplets reduces and the uniformity of water application increases as given in Appendix A-4 (9, 10, 11). At this pressure if the catch cans are overlapped at different spacings the UCC obtained will be lower than the UCC_{abb} but the mean depth of water in the catch can will be higher than the mean obtained from abbreviated column. This is because the depth of water in the catch cans considered are from one single column where the variation of water in the catch can is low because of lesser number of catch can values. In the case of microsprinkler the UCC_{abb} is less than UCC at 1.5 kg/cm² and 2.0 Kg/cm² because at this pressure the variation in the depth of water in the catch can near the microsprinkler and at the periphery of the wetted circular area is large. Due to this property of the micro sprinkler, it is always recommended that the overlapping of the microsprinkler should be equal to the radius of throw of the sprinkler jet. Those spacings at which any of the overlapped depths are equal to zero have not been considered due to its practical unacceptability.

4.3 Time of irrigation for crops grown on clay loam soil.

The irrigation period required for various crops in relation to clay loam soil, single nozzle, double nozzle overhead sprinkler and microsprinkler at different sprinkler operating pressures and sprinkler and lateral spacings are discussed.

4.3.1 Relation between depth of water in catch can and depth of soil moisture

Regression models were developed to determine the depth of moisture in the soil resulting from irrigation applied through single nozzle, double nozzle overhead sprinkler and microsprinkler operating at various pressures.

The relationship between the depth of water in catch can and soil moisture at a depth of 30 cm from single nozzle and double nozzle overhead sprinkler was determined by the best fit curve and was found to be linear with high R^2 values (coefficient of determination). Regression models for the determination

of the soil moisture depth at 2.0 kg/cm², 2.5 kg/cm², 3.0 kg/cm² and 3.5 kg/cm² for single nozzle overhead sprinkler are obtained in equation 4.1, 4.2, 4.3 and 4.4.

For 2.0 kg/cm²

$$SMd = 0.9822 CC_d - 1.9093 \quad (4.1)$$

$$R^2 = 0.9683$$

For 2.5 kg/cm²,

$$SMd = 0.9881 CC_d - 2.7312 \quad (4.2)$$

$$R^2 = 0.8648$$

For 3.0 kg/cm²,

$$SMd = 0.9807 CC_d - 1.7428 \quad (4.3)$$

$$R^2 = 0.9534$$

For 3.5 kg/cm²

$$SMd = 0.9653 CC_d - 0.8847 \quad (4.4)$$

$$R^2 = 0.939$$

Regression models for the determination of the soil moisture depth at 2.0 kg/cm², 2.5 kg/cm², 3.0 kg/cm² and 3.5 kg/cm² for double nozzle overhead sprinkler are obtained in equation 4.5, 4.6, 4.7 and 4.8.

For 2.0 kg/cm²

$$SMd = 0.9953 CC_d - 2.2638 \quad (4.5)$$

$$R^2 = 0.9922$$

For 2.5 kg/cm²

$$SMd = 1.0033 CC_d - 1.9667 \quad (4.6)$$

$$R^2 = 0.9944$$

For 3.0 kg/cm²

$$SMd = 0.9049 CC_d - 0.4785 \quad (4.7)$$

$$R^2 = 0.9791$$

For 3.5 kg/cm²

$$SMd = 0.9363 CC_d - 1.234 \quad (4.8)$$

$$R^2 = 0.9916$$

Regression models for the determination of the soil moisture depth at 1.0 kg/cm², 1.5 kg/cm², 2.0 kg/cm² and 2.5 kg/cm² for double nozzle overhead sprinkler are obtained in equation 4.9, 4.10 and 4.11.

For 1.0 kg/cm²

$$SMd = 0.7648 CC_d - 0.3507 \quad (4.9)$$

For 1.5 kg/cm²

$$SMd = 0.8231 CC_d - 0.8205 \quad (4.10)$$

For 2.0 kg/cm²

$$SMd = 0.8453 CC_d - 0.7836 \quad (4.11)$$

The mean depth of overlapped soil moisture obtained from the mean depth of overlapped water in the catch can with the help of equation 4.1, 4.2, 4.3, 4.4, 4.5, 4.6, 4.7, 4.8, 4.9, 4.10 and 4.11 are given in table 4.1, 4.2 and 4.3.

Table No 4.1 Mean depth of overlapped soil moisture obtained from the mean depth of overlapped catchcan data at various pressure and overlapped area for single nozzle overhead sprinkler.

S. No.	Pressure kg/cm ²	Area (m ²)	UCC (%)	Mean (mm)	UCCsm (%)	Mean (mm)
1	2.0	15	88.99	389.47	88.99	380.62
		60	76.88	97.39	76.88	93.72
		80	78.35	73.03	78.35	69.82
		108	76.82	54.09	76.82	51.22
		180	70.48	32.46	70.48	29.97
2	2.5	15	95.73	468.27	95.73	459.96
		60	95.86	117.07	95.86	112.94
		80	91.69	87.80	91.69	84.02
		108	84.78	65.04	84.78	61.53
		180	83.08	39.02	83.08	35.83
		300	73.47	23.41	73.47	20.40
		360	77.27	19.51	77.27	16.55
3	3.0	15	97.98	707.33	97.98	689.00
		60	91.37	176.08	91.37	170.94
		80	90.40	132.06	90.40	127.77
		108	94.68	97.82	94.68	94.19
		180	81.45	58.69	81.45	55.82
		300	75.34	35.22	75.34	32.79
		360	79.34	29.35	79.34	27.04
4	3.5	15	96.23	923	96.23	890.99
		60	91.02	230.98	91.02	222.08
		80	91.97	173.24	91.97	166.39
		108	90.98	128.32	90.98	122.99
		180	88.99	76.99	88.99	73.44
		270	82.33	51.33	82.33	48.66
		360	77.93	38.50	77.93	36.28
		420	87.74	33.00	87.74	30.97

Table No 4.2 Mean depth of overlapped soil moisture obtained from the mean depth of overlapped catch can data at various pressure and overlapped area for double nozzle overhead sprinkler.

S. No.	Pressure kg/cm ²	Area (m ²)	UCC (%)	Mean (mm)	UCCsm (%)	Mean (mm)
1	2.0	15	94.14	395.67	94.14	391.54
		60	90.71	98.92	90.71	96.19
		80	91.27	74.19	91.27	71.57
		108	84.25	54.95	84.25	52.43
		180	87.72	32.97	87.72	30.55
2	2.5	15	95.81	533.67	95.81	533.46
		60	92.37	133.42	92.37	131.89
		80	90.03	100.06	90.03	98.43
		108	85.52	74.12	85.52	72.40
		180	81.45	44.47	81.45	42.65
3	3.0	15	97.73	791.60	97.73	715.84
		60	91.47	197.90	91.47	178.60
		80	87.94	148.43	87.94	133.83
		108	88.24	109.94	88.24	99.01
		180	85.37	65.97	85.37	59.21
		270	86.85	43.98	86.85	39.32
		360	84.93	32.98	84.93	29.37
		420	84.11	28.27	84.11	25.10
4	3.5	15	96.35	760.13	96.35	710.48
		60	90.30	190.03	90.30	176.69
		80	88.86	142.52	88.86	132.21
		108	91.51	105.57	91.51	97.62
		180	84.05	63.34	84.05	58.08
		270	86.41	42.23	86.41	38.31
		360	80.55	31.67	80.55	28.42

Table No 4.3 Mean depth of overlapped soil moisture obtained from the mean depth of overlapped catch can data at various pressures and overlapped area for micro sprinkler.

S. No.	Pressure kg/cm ²	Area (m ²)	UCC (%)	Mean (mm)	UCCsm (%)	Mean (mm)
1	1.0	4	94.51	278	94.51	212.26
		9	93.70	123.56	93.70	94.14
		16	86.69	69.50	86.69	52.80
		25	85.65	44.48	85.65	33.67
		36	83.67	30.89	83.67	23.27
2	1.5	4	94.54	229.00	94.54	187.67
		9	96.19	101.78	96.19	82.95
		16	91.59	52.25	91.59	46.30
		25	94.73	36.64	94.73	29.34
		36	84.75	25.44	84.75	20.12
3	2.0	4	94.61	112.51	94.61	94.32
		9	89.53	38.61	89.53	31.85
		16	92.14	30.13	92.14	24.68
		25	85.53	16.54	85.53	13.19
		36	84.39	12.31	84.39	9.62

From table 4.1, 4.2 and 4.3 it is seen that the value of UCC and UCCsm are same where as the mean depth of overlapped soil moisture is less than the mean depth of overlapped catchcan data. There is no difference in the value of UCC and UCCsm for any given pressure and spacing due to the fact that the percentage reduction in the values of the overlapped catchcan depths, after its incorporation in the models developed are same for all the points considered. The lesser values of overlapped soil moisture indicate the horizontal and vertical movement of sprinkled water. The horizontal and vertical movement of water in the soil is governed by the soil characteristics.

The time required to irrigate various crops with single, double nozzle sprinkler and microsprinkler at different operating pressure and selected spacings are given in table 4.4, 4.5 and 4.6. The available soil water in fraction, readily available soil water and the rooting depth (m), for crops grown in clay loam soil, considered in Table No. 4.4, 4.5 and 4.6 are given in Appendix A8.

The total depth of water required for one irrigation for the crops is also given in Appendix A-8. The time required for one irrigation has been determined from the mean overlapped soil moisture because in field condition the depth of water in catch can will always remain more than the soil moisture depth at any point of the wetted area.

Table No. 4.4: Time required for irrigation by single nozzle overhead sprinkler at various pressures.

S No.	Time required for irrigation (minute)				
	Pressure (kg/cm ²)	2.0	2.5	3.0	3.5
	Discharge (l/sec)	0.3	0.32	0.38	0.44
	$\delta l \times \delta s$ (m x m)	9 x 12	18 x 20	15 x 20	18 x 20
1.	ALFALFA	96.64	299.09	150.96	136.51
2.	BANANA	18.44	57.09	28.81	26.06
3	BARLEY	72.46	223.86	113.22	102.38
4	COTTON	116.49	360.54	181.97	164.56
5	GRAIN	70.28	217.52	109.78	99.28
6	GRASS	61.49	190.33	96.06	86.82
7	GROUND NUT	25.77	79.75	40.25	36.40
8	MAIZE	95.58	295.83	149.13	135.02
9	PEPPER	14.64	45.31	22.87	20.68
10	PINEAPPLE	22.84	70.69	35.68	32.26
11	SAFFLOWER	112.45	348.03	175.66	158.85
12	SORGHUM	96.64	299.09	150.96	136.51
13	SOY BEANS	57.1	176.73	89.20	80.66
14	SUNFLOWER	47.44	146.82	73.19	67.95
15	TOBACCO	20.49	63.44	32.02	28.95
16	TOBACCO (LATE)	68.52	212.08	107.04	96.80
17	WHEAT	67.35	209.36	105.67	95.55
18	RIPENING	205.58	636.25	321.13	290.40

Table No. 4.5: Time required for irrigation by double nozzle overhead sprinkler at various pressures.

S No.	Pressure (kg/cm ²)	Time required for irrigation (minute)			
		2.0	2.5	3.0	3.5
	Discharge (l/sec)	0.363	0.472	0.556	0.64
	δ l x δ s (m x m)	9 x 12	12 x 15	21 x 20	18 x 20
1.	ALFALFA	94.41	116.06	197.21	174.17
2.	BANANA	18.02	22.15	37.64	33.25
3	BARLEY	70.80	87.04	147.9	130.62
4	COTTON	113.80	139.9	237.72	209.95
5	GRAIN	68.66	84.4	143.42	126.67
6	GRASS	60.08	73.8	125.49	110.83
7	GROUND NUT	25.17	30.94	52.58	46.44
8	MAIZE	93.38	114.79	195.05	172.27
9	PEPPER	14.30	17.58	29.88	26.38
10	PINEAPPLE	22.31	27.43	46.61	41.16
11	SAFFLOWER	109.86	135.05	229.48	202.67
12	SORGHUM	94.41	116.06	197.21	174.17
13	SOY BEANS	55.78	68.58	116.53	102.92
14	SUNFLOWER	46.34	56.97	96.81	85.50
15	TOBACCO	20.02	24.61	41.80	36.94
16	TOBACCO (LATE)	66.94	82.29	139.84	123.50
17	WHEAT	66.08	81.24	138.04	121.92
18	RIPENING	200.83	246.18	419.52	370.51

Table No. 4.6: Time required for irrigation by microsprinkler at various pressures

S No.	Time required for irrigation (minute)			
	Pressure (kg/cm ²)	1.0	1.5	2.0
	Discharge (l/sec)	0.113	0.0194	0.025
	Plot size (m x m)	6 x 6	6 x 6	6 x 6
1.	BEANS	48.9	56.36	117.87
2.	BEETS	90.24	104.37	218.29
3	CABBAGE	212.72	246.02	515.55
4	CITRUS	135.36	156.56	327.44
5	CLOVER	40.61	46.96	98.23
6	CACAO	108.29	125.24	261.95
7	CUCUMBER	108.48	208.74	436.54
8	DEC ORCHARDS	90.24	104.37	218.29
9	GRAPES	15.47	17.89	37.42
10	LETTUCE	67.68	78.28	163.72
11	MELONS	270.67	313.04	654.72
12	OLIVES	11.28	13.04	27.28
13	ONIONS	45.12	52.18	109.14
14	PEAS	11.60	13.41	28.69
15	POTATOES	7.73	8.94	18.71
16	SPINACH	2.32	2.68	5.61
17	STRAWBERRIES	108.29	125.24	261.95
18	SWEET POTATOES	226.25	261.67	547.29
19	TOMATO	92.82	107.35	224.53
20	VEGETABLE	9.282	10.735	22.45

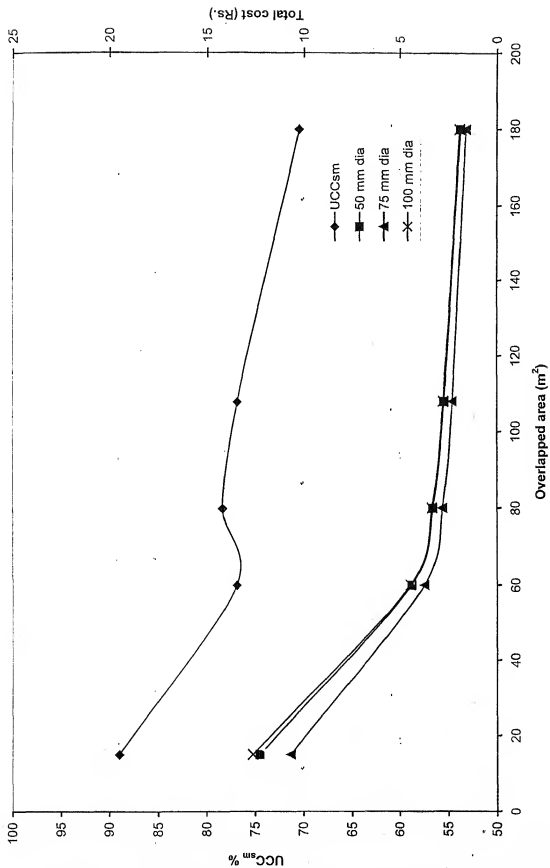


Fig. 4.13 Relationship between UCC_{sm} (%) overlapped sprinkler area (m²) and total annual cost (Rs.) for single nozzle overhead sprinkler operating at 2.0 Kg/cm².

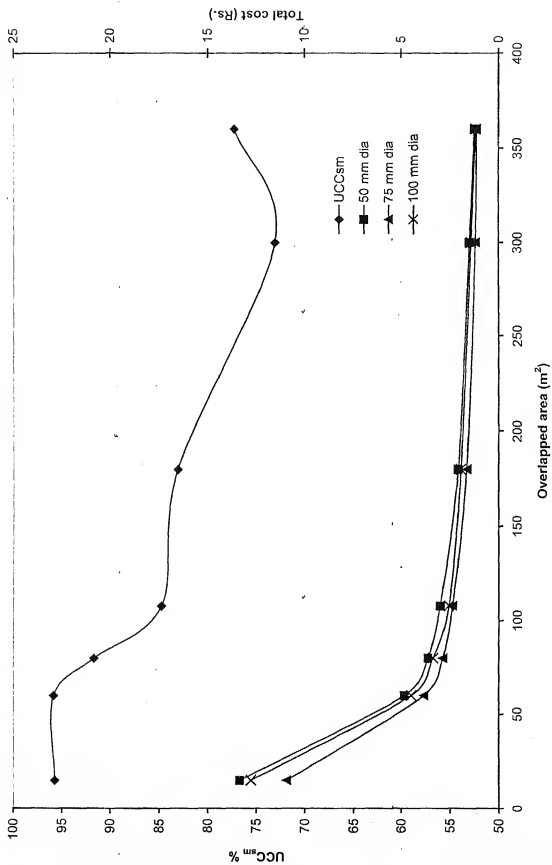


Fig. 4.14 Relationship between UCC_{sm} (%) overlapped sprinkler area (m²) and total annual cost (Rs.) for single nozzle overhead sprinkler operating at 2.5 Kg/cm².

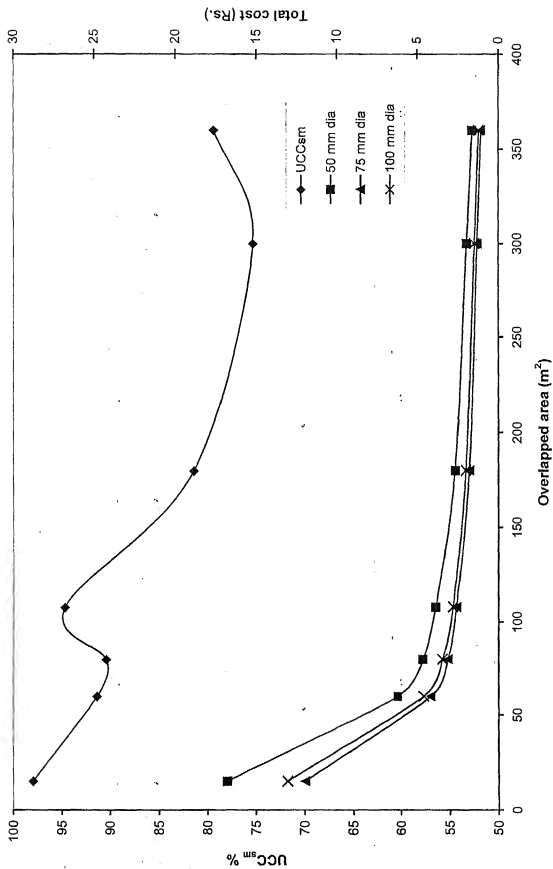


Fig. 4.15 Relationship between UCC_{sm} (%) overlapped sprinkled area (m²) and total annual cost (Rs.) for single nozzle overhead sprinkler operating at 3.0 Kg/cm².

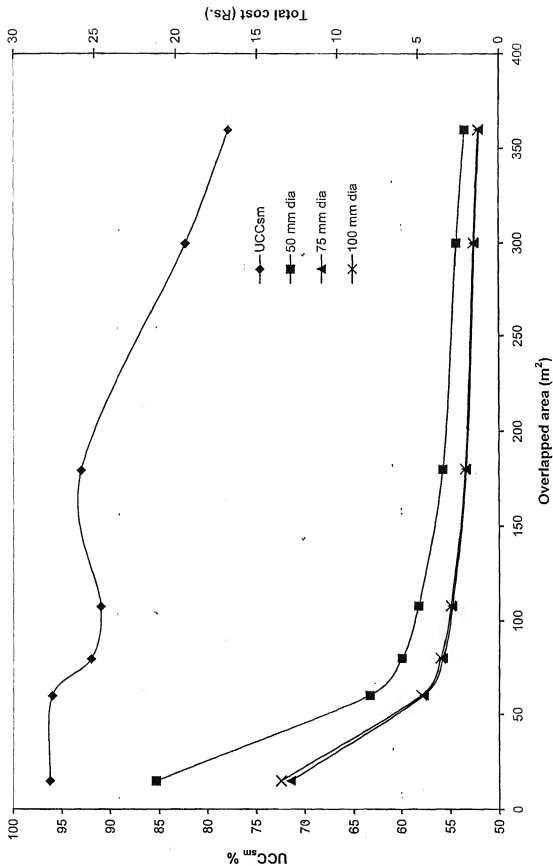


Fig. 4.16 Relationship between UCC_{sm} (%) overlapped sprinkler area (m²) and total annual cost (Rs.) for single nozzle overhead sprinkler operating at 3.5Kg/cm².

Hence the time of irrigation determined for one irrigation is based on the rate and the amount of horizontal and vertical movement of sprinkled water for clay loam soils and is governed by the principle of movement of water in soil under unsaturated conditions.

4.4 LATERAL COST

The total annual cost calculated for different pipe diameter, operating pressure and spacings are given in tables of Appendix A-7 (1-11). The cost per unit sprinkled area for aluminum pipe of 50 mm, 75 mm and 100 mm diameters for single and double nozzle overhead sprinklers and microsprinkler operating at different pressures and spacings are shown in Figure 4.13, 4.14, 4.15, 4.16, 4.17, 4.18, 4.19, 4.20, 4.21 and 4.23.

4.4.1 LATERAL COST FOR SINGLE NOZZLE OVERHEAD SPRINKLER

The total annual cost per unit sprinkled area for single nozzle overhead sprinkler operating at a pressure of 2.0 kg/cm², 2.5 kg/cm², 3.0 kg/cm², 3.5 kg/cm², with lateral diameter of 50 mm, 75 mm and 100mm is shown in Figure 4.13, 4.14, 4.15 and 4.16 and given in appendix A7 (1-11) from Figure 4.13 it can be seen that for an operating pressure of 2 kg/cm², an overlapped area of 15 m² and lateral diameter of 50 mm the total annual cost per unit sprinkled area is Rs. 12.25. For 75 mm lateral diameter and same overlapped area this cost is reduced by 12.89% and for 100mm lateral diameter it increases by 2.85 % when compared with 50 mm lateral diameter.

For an overlapped area of 60m², 80 m², 108 m² and 180 m², this cost increases by almost 15% when lateral diameter size increases from 50 mm to 75 mm. As the pipe size is increased from 50 mm to 100 mm it is observed that for 60 m², 80 m², 108 m² and 180 m², the cost increases by 1.59%, 1.82%, 1.47% and 2.13% respectively.

From figure 4.14 it can be observed that for an operating pressure of 2.5 kg/ cm², an overlapped area of 15 m² and a lateral diameter of 50mm the

total annual cost per unit sprinkled area is Rs. 13.33. For 75 mm and 100 mm lateral diameter and same overlapped area this cost reduces by 18.07% and 4.35% respectively. As the lateral diameter is increased from 50 mm to 75 mm this cost reduces and varies between 20.13% and 21.25% for an overlapped area of 60 m², 80 m², 108 m², 180 m² and 300 m². For an overlapped area of 360 m² if the lateral diameter is increased from 50 mm to 75mm the cost reduces by 8.87%. As the lateral diameter is increased from 50 mm to 100 mm this cost reduces by 7.23%, 7.16%, 15%, 6.76%, 5.36% and 4.83% for an overlapped area of 60 m², 80 m², 108 m², 180 m², 300 m² and 360m² respectively.

From figure 4.15 it can be observed that for an operating pressure of 3.0kg /cm², as the lateral diameter area increases from 50mm to 75mm the total annual cost per unit sprinkled reduces by almost 32% for all the overlapped areas. Further when the lateral diameter is increased to 100 mm this cost reduces by 25% when compared with 50 mm lateral diameter. For all the overlapped areas the total annual cost per unit sprinkled area is higher for 100 mm lateral diameter when compared with 75 mm lateral diameter.

From figure 4.16 it is observed that at an operating pressure of 3.5 kg/cm², as the lateral diameter increases from 50 mm to 75 mm the total annual cost per unit sprinkled area reduces by almost 41% for all the overlapped areas. Further when the lateral diameter is increased from 50 mm to 100 mm this cost reduces by 39% for all the overlapped areas.

4.4.2 LATERAL COST FOR DOUBLE NOZZLE OVER HEAD SPRINKLER

The total annual cost per unit sprinkled area for double nozzle over head sprinkler operating at a pressure of 2.0 kg/cm², 2.5 kg/cm², 3.0 kg/cm² and 3.5 kg/cm² with lateral diameter of 50 mm, 75 mm and 100 mm is shown in Fig. 4.17

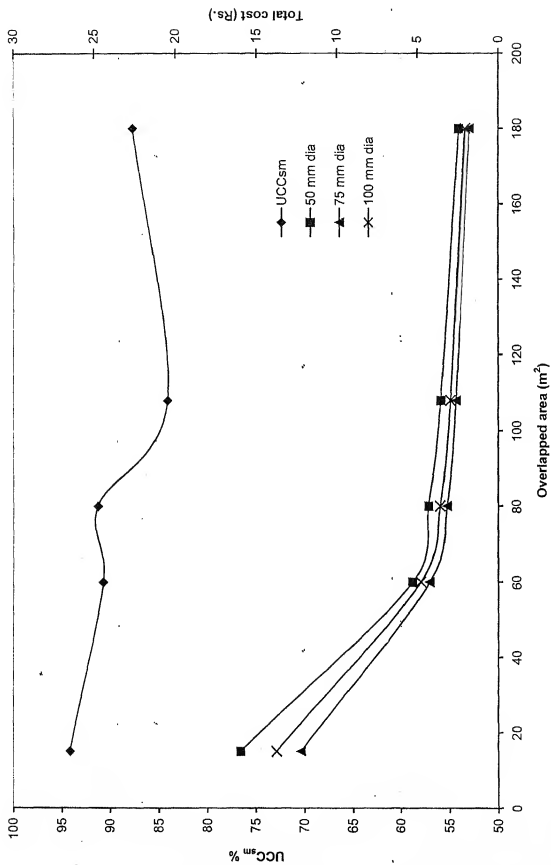


Fig. 4.17 Relationship between UCC_{sm} (%) overlapped sprinkler area (m²) and total annual cost (Rs.) for double nozzle overhead sprinkler operating at 2.0 Kg/cm².

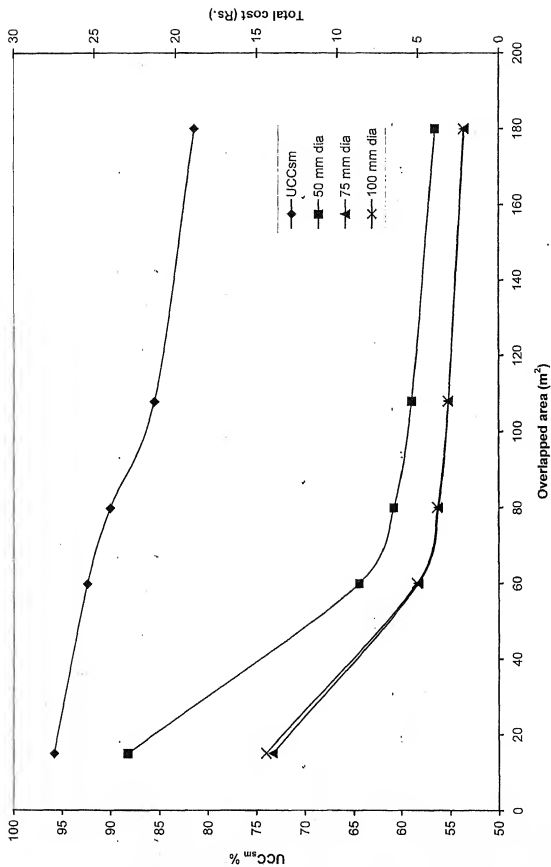


Fig.4.18 Relationship between $UCC_{sm} \%$ overlapped sprinkler area (m^2) and total annual cost (Rs.) for double nozzle overhead sprinkler operating at 2.5 Kg/cm^2 .

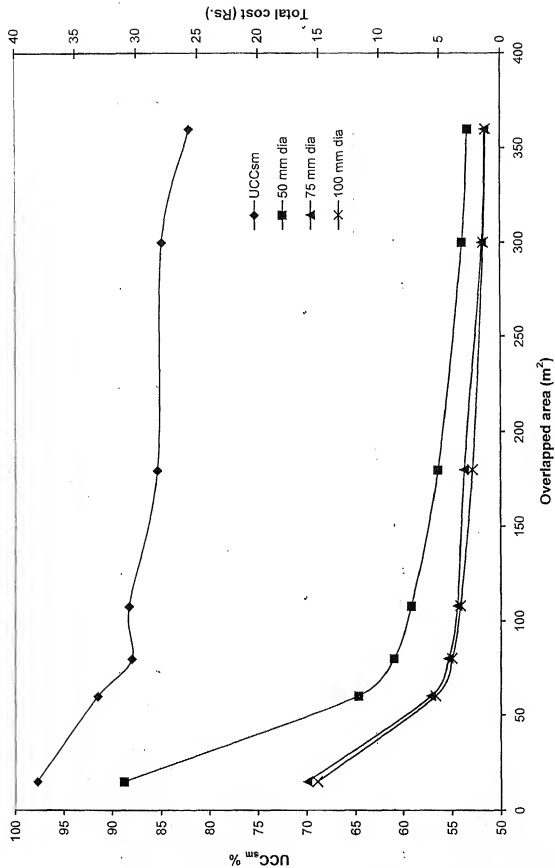


Fig. 4.19 Relationship between UCC_{sm} (%) overlapped sprinkler area (m²) and total annual cost (Rs) for double nozzle overhead sprinkler operating at 3.0 Kg/cm².

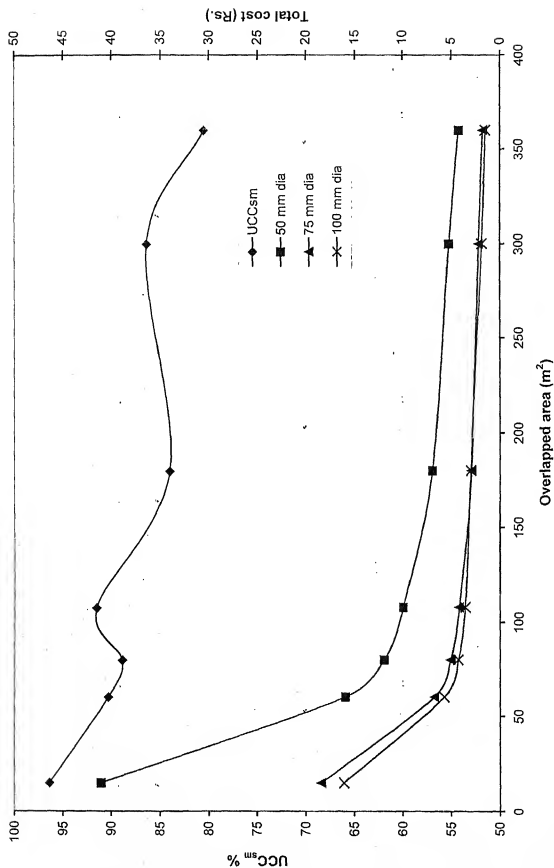


Fig. 4.20 Relationship between UCC_{sm} (%) overlapped sprinkler area (m^2) and total annual cost (Rs.) for double nozzle overhead sprinkler operating at 3.5 Kg/cm^2 .

4.18, 4.19 and 4.20. From figure 4.17 it is observed that for an overlapped area of 15m^2 and 60m^2 as the lateral diameter is increased from 50 mm to 75 mm the cost reduces by 23.41% and 20.11% respectively. As the lateral diameter increases from 50 mm to 100 mm for the same overlapped area the cost reduces by 13.93% and 9.48%. For an overlapped area of 80m^2 , 108m^2 and 180m^2 as the lateral diameter is increased from 50 mm to 75mm and 100 mm the cost reduces by about 26% and 16% respectively.

For all the overlapped areas the total annual cost per unit wetted area for 100 mm lateral diameter is more than the cost for 75 mm lateral diameter. From figure 4.18 it is observed that for all the overlapped areas and an operating pressure of 2.5 kg/cm^2 the total annual cost for 75 mm lateral diameter, when compared with 50 mm lateral diameter is less by almost 42%. Further this cost reduces by about 41% when the lateral diameter is increased from 50 mm to 100mm. For all the overlapped areas the total annual cost per unit sprinkled area for 100mm lateral diameter is more than the cost for 75mm lateral diameter but it is opposite in the case when the lateral diameter is reduced from 75mm to 50 mm.

From figure 4.19 it is observed that for an operating pressure of 3.0kg/cm^2 and for all the overlapped areas, as the lateral diameter is increased from 50 mm to 75mm the total annual cost per unit sprinkled area reduces by 51%. As the lateral diameter is increased from 50mm to 100mm, for all the overlapped areas the cost further reduces to 55%.

From fig 4.20 it is observed that for an operating pressure of 3.5kg/cm^2 and for all the overlapped areas, as the lateral diameter is increased from 50 mm to 75mm the total annual cost pre unit sprinkled area reduces by 57%. As the lateral diameter is increased from 50mm to 100mm for all the overlapped areas the cost further reduces to 64%.

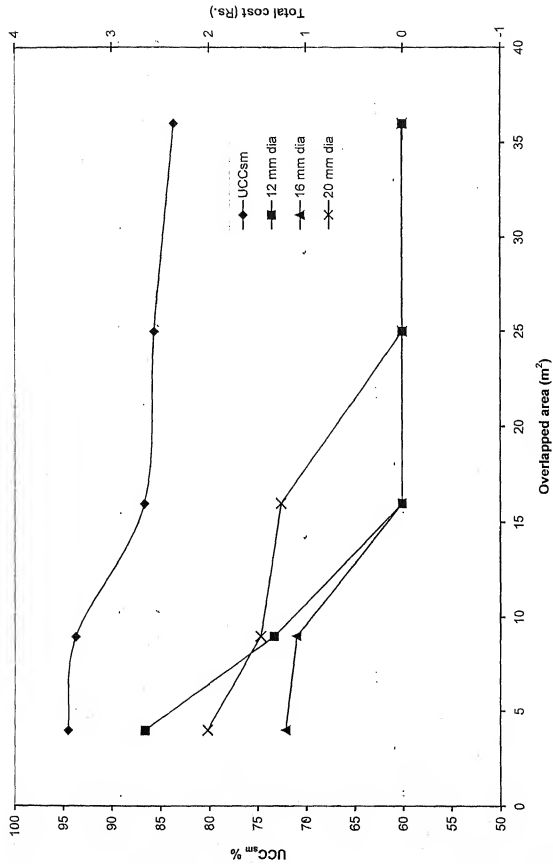


Fig. 4.21 Relationship between UCC_{sm} (%) overlapped sprinkler area (m^2) and total annual cost (Rs.) for microsprinkler operating at 1.0 Kg/cm^2 .

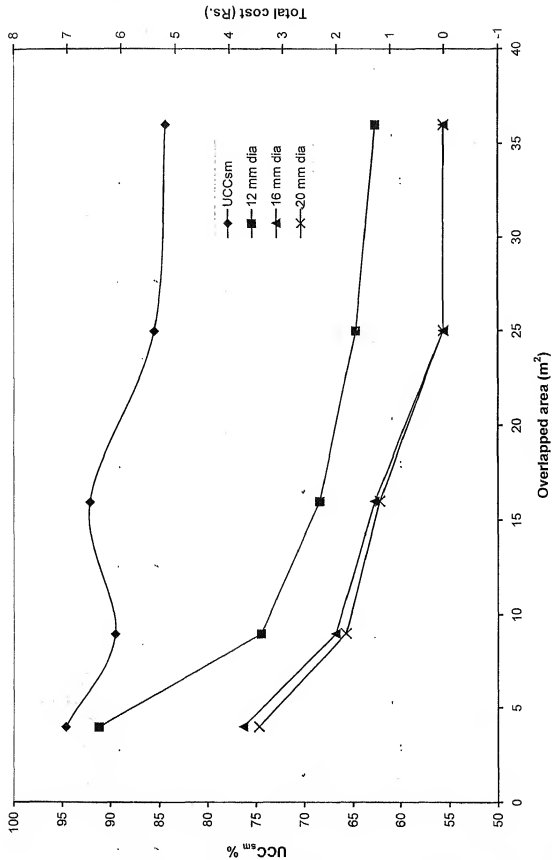


Fig. 4.23 Relationship between UCC_{sm} (%) overlapped sprinkler area (m^2) and total annual cost (Rs.) for microsprinkler operating at 2.0 Kg/cm^2 .

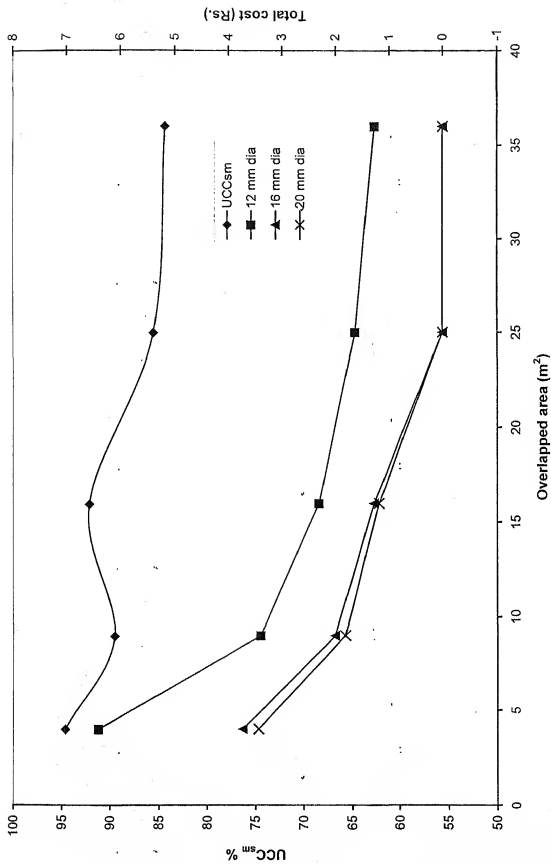


Fig. 4.23 Relationship between UCC_{sm} (%) overlapped sprinkled area (m^2) and total annual cost (Rs.) for microsprinkler operating at 2.0 Kg/cm^2 .

4.4.3. LATERAL COST FOR MICROSPRINKLER

The total annual cost per unit sprinkler area for micro-sprinkler operating at a pressure of 1.0kg/cm^2 , 1.5 kg/cm^2 and 2kg/cm^2 with a lateral diameter of 12mm, 16mm and 20mm is shown in figure 4.21, 4.22 and 4.23 and given in Appendix A7 (1- 11).

From figure 4.21 it is observed that as the lateral diameter is increased from 12mm to 16mm the total annual cost per unit sprinkled area for an overlapped area of 4m^2 , 6m^2 , 16m^2 , 25m^2 and 36m^2 reduces by 20.67%, 9.02%, 10.71%, 10.34% and 9.30% respectively. As the lateral diameter is increased from 12mm to 20mm for all the overlapped areas this cost increases by 6.01%, 10.52%, 51.79%, 17.24% and 23.25% respectively.

From Figure 4.22 it is observed that as the lateral diameter is increased from 12mm to 16mm the total annual cost per unit sprinkled area for an overlapped area of 4m^2 , 6m^2 , 16m^2 , 25m^2 and 36m^2 reduces by 29.9%, 32.31%, 99.33%, 99.34% and 35.36% respectively. This cost also reduces by 29.6%, 28.38%, 28.58%, 99.28% and 28.04% as the lateral diameter is increased from 12mm to 20mm for all the overlapped areas.

From figure 4.23 it is observed that as the lateral diameter is increased from 12mm to 16mm the total annual cost per unit sprinkled area for an overlapped area of 4m^2 , 6m^2 , 16m^2 , 25m^2 and 36m^2 reduces by 41.80%, 40.90%, 44.39%, 99.43% and 99.44% respectively. As the lateral diameter is increased from 12 mm to 20mm for all the overlapped areas this cost reduces by 46.33%, 48.27%, 48.27%, 99.47% and 99.46% respectively.

4.4.4 Selection of economical lateral diameter.

The selection of economical lateral diameter is done by firstly considering the acceptable UCC_{sm} . That overlapped sprinkled area is considered which has a value of UCC_{sm} equal to 75% or more. From Figure 4.13 for an overlapped area of 108m^2 and spacing of $9\text{m} \times 12\text{m}$, the UCC_{sm} is 76.82% for

an operating pressure of 2.0 kg/cm^2 . At this spacing the most economical lateral diameter is 100 mm. The total numbers of single nozzle overhead sprinklers will be 35, the permissible length will be 424m and the total cost per unit sprinkled area will be Rs. 2.75 .

From figure 4.14 for an overlapped area of 360 m^2 and spacing of $18\text{m} \times 20\text{m}$ the UCCsm is 77.27% for an operating pressure of 2.5 kg/cm^2 . At this spacing the most economical lateral diameter will be 100mm. The total number of single nozzle overhead sprinklers on this lateral line will be 30, the length of the lateral line will be 612 m and the total cost per unit sprinkled area will be Rs. 1.18 .

From figure 4.15 for an overlapped area of 300 m^2 and spacing of $15\text{m} \times 20\text{m}$ the UCCsm is 75.4% for an operating pressure of 3.0 kg/cm^2 . At this spacing the most economical lateral diameter will be 75mm. The total number of single nozzle overhead sprinklers on this lateral line will be 18, the length of the lateral line will be 357m and the total cost per unit sprinkled area will be Rs. 1.30.

From figure 4.16 for an overlapped area of 360 m^2 , an operating pressure of 3.5 Kg/cm^2 and a spacing of $18\text{m} \times 20\text{m}$ the UCCsm is 87.74%. The most economical lateral diameter will be 75mm. The total number of single nozzle overhead sprinklers on this lateral line will be 17, the length of the lateral line will be 343m and the total cost per unit sprinkled area will be Rs. 1.20 .

From figure 4.17 for an overlapped area of 108 m^2 and spacing of $9\text{m} \times 12\text{m}$ and an operating pressure of 2.0 kg/cm^2 the UCCsm was observed to be 84.25%. At this spacing the most economical lateral diameter is observed to be 100mm. The total numbers of double nozzle overhead sprinklers on this lateral line will be 31, its length 374m and the total cost per unit sprinkled area will be Rs. 2.14 .

From figure 4.18 for an overlapped area of 180 m^2 and spacing of $12\text{m} \times 15\text{m}$ and an operating pressure of 2.5 kg/cm^2 the UCCsm was observed to be 81.45%. At this spacing the most economical lateral diameter is observed to be 100mm. The total numbers of double nozzle overhead sprinklers on this lateral line will be 26, the total length 394m and the total cost per unit sprinkled area will be Rs. 2.15 .

From figure 4.19 for an overlapped area of 420 m^2 and spacing of $21\text{m} \times 20\text{m}$ and an operating pressure of 3.0 kg/cm^2 the UCCsm was observed to be 84.11%. At this spacing the most economical lateral diameter is observed to be 100mm. The total numbers of double nozzle overhead sprinklers on this lateral line will be 23, the length of the lateral line will be 456m and the total cost per unit sprinkled area will be Rs. 1.19 .

From figure 4.20 for an overlapped area of 360 m^2 and spacing of $18\text{m} \times 20\text{m}$ and an operating pressure of 3.5 kg/cm^2 the UCCsm was observed to be 80.55%. At this spacing the most economical lateral diameter is observed to be 100mm. The total numbers of double nozzle overhead sprinklers on this lateral line will be 22, for a lateral length of 439m and the total cost per unit sprinkled area will be Rs. 1.49 .

From figure 4.21, at a pressure of 1.0Kg/cm^2 and for an overlapped area of 36 m^2 and spacing of $6\text{m} \times 6\text{m}$ the UCCsm was observed to be 83.67%. At this spacing the most economical lateral diameter is observed to be 16mm. The total numbers of microsprinklers on this lateral length of 77m will be 13 and the total cost will be Rs. 3952/ha.

From figure 4.22 for an overlapped area of 36 m^2 and spacing of $6\text{m} \times 6\text{m}$ the UCCsm was observed to be 84.75%. At this spacing the most economical lateral diameter is observed to be 16mm. The total numbers of microsprinklers on this lateral length of 63m will be 11 and the total cost will be Rs. 5330/ha.

The information given in Table 4.7 can be taken as a guideline for deciding the length of economical lateral diameter under different field conditions. The information given about the abbreviated uniformity coefficient and UCC was higher than the economical spacing recommended by Gohring and Willander (1987). The recommendation given for the time period required for irrigating various crops can be useful to the farmers. Similar analysis for different makes and models can be carried out with the help of developed software for designing economical lateral diameter.

CHAPTER - V

SUMMARY AND CONCLUSION

SUMMARY AND CONCLUSION

The main objective of this study was to develop a computer aided selection methodology for selecting economic sprinkler and micro sprinkler lateral for clay loam soil in such a way that the uniformity coefficient, abbreviated uniformity coefficient, and soil moisture uniformity was maximum with minimum total annual cost. Comparative evaluation of abbreviated overhead sprinkler and microsprinkler with UCC, was done to abbreviate the method used to calculate the uniformity of sprinkled water. The depth of water required to irrigate various crops grown in clay loam soil was obtained. The single leg catch can data was obtained by operating single nozzle, double nozzle overhead sprinkler and micro sprinkler at different operating pressures. A computer software was developed in Fortran-77 to calculate the Christian Uniformity coefficient, abbreviated uniformity coefficient, soil moisture uniformity, overlapped abbreviated mean depth of soil moisture, numbers of sprinklers on a lateral live, total length of lateral live and total annual cost for per unit sprinkler area for different lateral diameter. The total annual cost included the fixed and energy cost. The fixed cost of the, lateral included the cost of pipe, sprinkler heads, risers, couplers in the total length of the live. Finally the selection of the economical sprinkler was made by considering uniformity and total annual cost per unit sprinkler area. Based on this study the following summary of results, conclusions and recommendations are given.

5.1 Summary of results

5.1.1 Computer software

The computer software develop for the computation of overlapped pattern and UCC for single nozzle, double nozzle sprinkler and microsprinkler for any given operating pressure and sprinkler and lateral spacing. The software computes the uniformity by converting quarter circle catch can data

obtained from one single overhead sprinkler into full circle and gives the desired number of catch can data at any desired spacing thereafter it calculates the UCC, UCC_{abb} , UCC_{sm} and the total operating cost per unit sprinkled area.

5.1.2 Abbreviated overhead sprinkler uniformity

1. Single nozzle overhead sprinkler

The relationship obtained between the UCC and UCC_{abb} obtained for different operating pressures and spacings for single nozzle overhead sprinkler has been discussed in section 4.2.1 from fig. 4.2, 4.3, 4.4 and 4.5 it can be seen that at lesser spacing the value of UCC_{abb} is always high for all four sprinkler operating pressure enhances, as the spacing between the sprinkler and lateral increases the total of catch can increases, taking into account those catch can which are at the periphery of the wetted circular area obtained by sprinkling the water from the sprinkler, thus reducing the depth of water in the overlapped area.

2. Double nozzle over head sprinkler

The relationship obtained between the UCC and UCC_{abb} obtained for different operating pressure and spacings for double nozzle overhead sprinkler has been discussed in section 4.2.2. The agreement between the UCC and UCC_{abb} has been found good for all the four operating pressures as shown in figure 4.6, 4.7, 4.8 and 4.9.

3. Microsprinkler

The relationship obtained between the UCC and UCC_{abb} obtained for different operating pressure and spacings for double nozzle overhead sprinkler has been discussed in section 4.2.3. In the case of microsprinkler the UCC_{abb} is less than UCC at 1.5 kg/cm^2 and 2.0 Kg/cm^2 because at this pressure the variation in the depth of water in the catch can near the

microsprinkler and at the periphery of the wetted circular area is large. Due to this property of the micro sprinkler, it is always recommended that the overlapping of the microsprinkler should be equal to the radius of throw of the sprinkler jet. Those spacings at which any of the overlapped depths are equal to zero have not been considered due to its practical unacceptability. This can be seen from figure 4.10, 4.11 and 4.12 respectively.

5.1.3 Time of Irrigation

One of the most important parameter in designing the pressurized irrigation system is to understand the relationship between the depth of water caught in catch can and the resulting increase or decrease in the depth of soil moisture in the desired area. It was found that for single nozzle, double nozzle over head sprinkler and microsprinkler, for all spacings and operating pressures the mean depth of water caught in catch can was always higher than the mean soil moisture depth due to the fact that the water moves horizontally and vertically in the soil, whereas this movement is restricted in the case of water collected in catch cans as given in Tables 4.1, 4.2 and 4.3. Thus based on this observation the water requirement of various crops and the total time required for one irrigation has been given in table no. 4.4, 4.5, and 4.6.

5.1.4 LATERAL COST

The total annual cost calculated for different pipe diameter, operating pressure and spacings are given in tables of Appendix A-7 (1-11). The cost per unit sprinkled area for aluminum pipe of 50 mm, 75 mm and 100 mm diameters for single and double nozzle overhead sprinklers and microsprinkler operating at different pressures and spacings are shown in Figure 4.13, 4.14, 4.15, 4.16, 4.17, 4.18, 4.19, 4.20, 4.21 and 4.23. and discussed in Section 4.4.

5.1.4.1 Selection of Economical lateral diameter

The economics of using 50mm, 75mm and 100mm diameter lateral for overhead single and double nozzle sprinkler and 12mm, 16mm and 20mm diameter lateral for microsprinkler has been given in Table no.4.7.

The information given in Table 4.7 can be taken as a guideline for deciding the length of economical lateral diameter under different field conditions. The information given about the abbreviated uniformity coefficient and UCC was higher than the economical spacing recommended by Gohring and Willander (1987). The recommendation given for the time period required for irrigating various crops can be useful to the farmers. Similar analysis for different makes and models can be carried out with the help of developed software for designing economical lateral diameter.

The following conclusions were drawn:

- i) The abbreviated uniformity coefficient obtained from a nozzle overhead sprinkler is acceptable for a wide range of lateral and sprinkler spacing when the operating pressure is high.
- ii) The abbreviated uniformity coefficient obtained from a double nozzle overhead sprinkler is acceptable for a wide range of lateral and sprinkler spacing and pressures
- iii) The abbreviated uniformity coefficient obtained from a micro sprinkler is acceptable only at lower pressures and up to a 100 % overlapped method diameter.

The following recommendations should be referred to while designing a sprinkler or microsprinkler irrigation system:

1. A minimum of 50 % overlapped wetted diameter, at a sprinkler operating pressure of 3.0 kg / cm² is recommended for irrigating the crops using a single nozzle or- double nozzle overhead sprinkler.

2. A minimum of 50 % overlapped wetted diameter at an operating pressure of 1.0 kg/cm² is recommended for irrigating the crops by micro sprinkler.
3. It is recommended that selection of the most economical sprinkler lateral diameter at any sprinkler operating pressure should be based on a minimum soil moisture uniformity of 75 % and corresponding maximum length of the lateral line.

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APPENDIX

APPENDIX A – 1

Sieve analysis of soil sample taken in the experimental plot

Soil sample No. 1

Soil weight 500 gm.

Mesh No.	Diameter of particles (mm)	Mass Retained (gm)	Corrected retained (gm)	Percentage retained	Cumulative retained (%)
200	0.127	2.5	2.51	0.502	0.502
50	0.508	190.0	190.76	36.152	36.654
25	1.016	84.0	84.34	16.87	55.529
15	1.693	20	20.08	4.02	59.54
8	3.125	0.5	0.502	0.1	59.64
Pan		201	201.8	40.36	100
	Total	498	500		

Soil sample No. 2

Soil weight 500 gm.

Mesh No.	Diameter of particles (mm)	Mass Retained (gm)	Corrected retained (gm)	Percentage retained	Cumulative retained (%)
200	0.127	5.2	5.22	1.09	0.104
50	0.508	176.0	176.81	35.36	36.40
25	1.016	114.0	114.52	22.90	59.30
15	1.693	23.0	23.10	4.62	63.92
8	3.175	2.5	2.51	0.502	68.54
Pan	-	177.0	177.81	35.56	104.1
	Total	497.7	500		

APPENDIX – A2

Determination of field capacity.

S. No.	Depth (cm)	Wet weight (gm)	Dry weight (gm)	Moisture content (%)
1.	10	59.63	48.17	23.79
2.	20	86.70	37.15	25.70
3.	30	86.47	71.21	21.43

APPENDIX – A3

Determination of bulk density.

S. No.	Depth (cm)	Wet weight (gm)	Dry weight (gm)	Bulk density (gm/cc)
1.	10	450.5	420.0	1.30
2.	20	548.0	497.0	1.54
3.	30	587.0	522.0	1.62

Appendix - A4 (1)

Duration : OneHour
 Pressure : 2.0 kg/cm²
 Nozzle Type : Single
 Range : 9.45 m
 Discharge : 0.3 l/sec

20	20	18	13	10	15	20	24	17	3
19	13	12	10	10	15	24	22	16	2
10	10	11	10	9	14	26	18	15	0
10	10	11	11	11	11	32	23	12	0
13	11	12	13	16	14	22	33	10	0
17	17	16	18	21	27	34	39	8	0
23	28	25	32	35	34	35	29	3	0
18	32	38	35	36	32	14	9	0	0
11	18	13	13	13	13	7	1	0	0
3	5	4	3	3	0	0	0	0	0

Appendix - A4 (4)

Duration : One hour
 Pressure : 3.5 kg/cm²
 Nozzle type : Single
 Range : 14 m
 Discharge : 0.44 l/sec

20	20	18	16	27	19	22	25	27	26	22	219	25	9
23	22	21	15	14	15	28	21	24	26	26	24	21	15
20	22	19	15	15	16	27	21	22	25	26	25	20	14
19	17	15	15	16	16	19	22	25	28	26	24	17	15
21	20	17	16	18	18	21	24	27	25	26	25	18	9
27	25	22	20	22	23	24	27	28	26	25	24	12	3
23	30	28	28	27	26	26	27	28	26	24	22	16	10
25	34	32	31	30	28	27	27	28	22	23	18	15	12
32	23	33	32	30	28	26	25	23	18	19	12	9	8
26	30	30	29	29	25	24	23	17	12	11	8	3	0
20	24	27	26	26	22	20	21	9	10	7	0	0	0
12	15	19	18	17	18	14	12	3	2	0	0	0	0
10	14	10	12	9	8	5	10	0	0	0	0	0	0
8	6	8	3	2	0	0	0	0	0	0	0	0	0

Appendix - A4 (5)

Duration : One hour
 Pressure : 2.0 kg/cm²
 Nozzle type : double
 Range : 9.45 m
 Discharge:
 Spreader : 0.108 l/sec
 Ranger : 0.255 l/sec
 Total = 0.363 l/sec..

48	50	44	25	16	13	17	6	11	8	0
39	21	36	22	16	17	18	14	18	20	6
30	34	22	17	15	17	15	15	21	11	3
17.5	17	17	16	16	17	11	17	19	9	0
13	15	17	17	17	13	18	23	12	5	0
15	18	20	20	13	16	29	24	10	1	0
10	16	14	15	19	20	18	12	2	0	0
13	15	16	21	23	19	8	4	0	0	0
15	15	14	17	11	8	1	0	0	0	0
5	7	3	4	2	0	1	0	0	0	0

Appendix - A4 (6)

Duration	:	One hour
Pressure	:	2.5 kg/cm ²
Nozzle Type	:	Double
Range	:	10.5 m
Discharge:		
Spreader	:	0.157 l/sec
Ranger	:	0.315 l/sec
Total	=	0.472 l/sec

45	42	29	21	22	20	15	15	10	3
38	78	28	21	23	25	24	21	18	6
45	35	23	22	25	28	27	22	14	3
24	23	25	25	30	31	28	21	12	2
20	22	26	31	33	35	27	15	3	1
21	25	30	35	36	32	22	10	2	1
25	33	36	38	23	20	12	6	1	0
30	37	42	35	25	14	6	3	0	0
35	29	25	19	11	8	2	1	0	0
20	23	11	11	5	2	0	0	0	0
7	6	3	2	0	0	0	0	0	0

Appendix - A4 (7)

Duration	:	One hour
Pressure	:	3.0 kg/cm ²
Nozzle type	:	Double
Range	:	12.8 m
Discharge		
Spreader	:	0.188 l/sec
Ranger	:	0.368 l/sec
Total	=	0.556 l/sec

[illegible]

Appendix - A4 (8)

Duration : One hour
 Pressure : 3.5 kg/cm²
 Nozzle type : Double
 Range : 14 m
 Discharge:
 Spreader : 0.207 l/sec
 Ranger : 0.433 l/sec
 Total = 0.640 l/sec

40	36	47	29	22	20	18	16	17	26	16	12	4
30	46	48	26	21	20	20	21	21	16	29	25	11
88	45	30	32	20	19	21	21	21	23	23	18	7
25	23	21	19	20	19	20	20	23	27	26	16	6
19	19	17	17	18	18	18	18	23	25	26	15	0
15	17	17	17	18	19	18	20	23	21	21	11	0
15	15	17	17	17	18	18	23	26	21	17	6	0
15	16	17	18	18	19	20	24	21	22	8	3	0
15	16	15	16	17	19	21	24	13	15	5	0	0
13	17	17	19	20	23	24	19	5	5	0	0	0
14	17	18	18	23	24	17	15	13	0	0	0	0
13	22	21	23	23	18	8	0	3	0	0	0	0
12	16	15	14	6	0	0	0	0	0	0	0	0
5	7	7	5	0	0	0	0	0	0	0	0	0

Appendix – A4 (9)

Duration : One Hour
 Pressure : 1.0 kg/cm²
 Range : 3.5 m
 Nozzle type : Microsprinkler
 Discharge : 0.0096 l/sec

5	6	5	8	8	16	5
4	4	4	6	8	20	6
8	4	4	7	10	18	2
9	8	8	10	15	7	0
11	11	13	11	5	0	0
3	4	3	2	0	0	0

Appendix – A4 (10)

Duration : One hour
 Pressure : 1.5 kg/cm²
 Nozzle type : Microsprinkler
 Range : 4.5 m
 Discharge : 0.0113 l/sec

9	3	3	3	2	4	3	3	3
10	2	2	3	3	4	4	3	2
7	4	2	4	4	4	6	4	2
6	5	4	6	6	5	5	2	0
8	6	6	6	5	3	3	0	0
6	6	6	6	4	2	0	0	0
4	5	5	3	3	0	0	0	0

Appendix – A4 (11)

Duration : One hour
 Pressure : 2.0 kg/cm²
 Nozzle type : Microsprinkler
 Range : 3.5 m
 Discharge : 0.015 l/sec

11	10	8	6	5	4	3	2
9	11	8	6	6	5	4	3
8	8	6	6	6	4	3	2
4	5	4	3	3	3	2	2
0	3	2	2	2	2	0	0

APPENDIX – A5 (1)

- i). Catch can data at an angle of 30° for an operating pressure of 2.0 kg/cm^2 for single nozzle overhead sprinkler.

20				
18				
11	11			
9	10			
14	11	14		
16	15	15		
24	30	25	35	
17	35	38	35	
10	19	14	15	14
4	4	5	3	3

- ii) Soil moisture depth at pressure of 2.0 kg/cm^2 for single nozzle overhead sprinkler

18				
15				
9	10			
8	8			
13	10	12		
14	14	13		
22	28	21	34	
15	33	35	33	
9	17	11	12	13
3	3	2	1	1

Appendix A-5 (2)

- i) Catch can data at an angle of 30^0 for an operating pressure of 2.5 kg/cm^2 for single nozzle overhead sprinkler.

21			
20			
14	30		
13	14		
14	14	15	
21	18	17	
18	22	20	25
23	24	25	19
23	20	18	20
14	20	15	12
10	10	9	8

- ii) Soil moisture depth at pressure of 2.5 kg/cm^2 for single nozzle overhead sprinkler.

18			
17			
12	27		
12	12		
12	13	12	
18	15	15	
15	18	18	21
20	21	24	24
22	15	17	22 17
12	17	12	17 9
7	7	6	3 6

Appendix A-5 (3)

- i) Catch can data at an angle of 30° for an operating pressure of 3.0 kg/cm^2 for single nozzle overhead sprinkler.

17					
18					
17	18				
18	18				
20	20	20			
25	24	20			
26	28	24	24		
30	30	27	30		
30	27	27	28	30	
17	24	25	14	25	
16	20	18	17	18	14
8	6	10	10	9	4
2	3	3			

- ii) Soil moisture depth at pressure of 3.0 kg/cm^2 for single nozzle overhead sprinkler.

14					
16					
14	16				
16	16				
28	18	18			
21	20	18			
25	26	21	21		
28	28	25	26		
28	25	26	25	28	
16	20	23	10	21	
14	17	16	15	15	12
6	4	9	8	7	3
1	1	1			

Appendix A-5 (4)

- i) **Catch can data at an angle of 30° for an operating pressure of 3.5 kg/cm^2 for single nozzle overhead sprinkler.**

20						
24						
18	22					
20	18					
22	19	18				
26	25	21				
23	32	27	27			
24	34	32	30			
33	23	32	31	30		
28	31	31	30	28		
20	25	28	28	26	22	
14	16	18	18	16	17	
10	14	10	12	9	8	5
7	6	8	3	2		

- ii) **Soil moisture depth at a pressure of 3.5 kg/m^2 for single nozzle overhead sprinkler.**

19						
23						
17	20					
18	17					
21	17	16				
25	26	20				
22	30	25	25			
22	32	30	28			
30	22	30	30	28		
26	30	30	28	26		
19	22	26	28	26	21	
13	14	16	16	25	16	
9	13	7	11	7	5	4
5	5	4	2	1		

Appendix A-5 (5)

- i) Catch can data at an angle of 30^0 for an operating pressure of 2.0 kg/cm^2 for double nozzle overhead sprinkler.

48				
39				
31	34			
18	20			
14	16	17		
14	18	20		
11	16	14	16	
12	15	18	22	
14	15	14	18	
3	8	5	4	3

- ii) Soil moisture depth at a pressure of 2.0 kg/m^2 for double nozzle overhead sprinkler.

45				
38				
28	32			
17	18			
13	14	15		
12	14	17		
8	14	12	14	
9	14	14	18	
10	13	12	16	
1	6	2	2	1

Appendix A-5 (6)

- i) Catch can data at an angle of 30° for an operating pressure of 2.5 kg/cm^2 for double nozzle overhead sprinkler.

43				
37				
42	36			
26	25			
22	23	28		
20	25	32		
24	32	33	38	
29	40	41	35	
33	25	26	20	12
22	22	12	13	10
9	3	3	0	3

- ii) Soil moisture depth at a pressure of 2.5 kg/m^2 for double nozzle overhead sprinkler.

42				
36				
40	34			
25	24			
21	22	27		
18	24	30		
21	31	30	35	
25	38	38	33	
31	24	25	18	10
19	21	10	12	8
5	3			

Appendix A-5 (7)

- i) Catch can data at an angle of 30^0 for an operating pressure of 3.0 kg/cm^2 for double nozzle overhead sprinkler.

40			
34			
84	71		
24	25		
18	20	22	
23	24	26	
22	25	26	
18	21	22	
22	19	22	21
22	18	18	20

- ii) Soil moisture depth at an operating pressure of 3.0 kg/m^2 for double nozzle overhead sprinkler.

38				
32				
63	68			
21	23			
16	18	20		
20	22	24		
20	22	24		
16	18	21		
20	17	21	18	
19	16	16	18	
20	18	18	19	
14	9	4	12	18
6	2	0	3	5

Appendix A-5 (8)

- i) Catch can data at an angle of 30^0 for an operating pressure of 3.5 kg/cm² for double nozzle overhead sprinkler.

42					
32					
85	45				
25	23				
20	20	18			
16	17	18			
16	16	17	18		
16	15	16	16		
15	15	16	16	16	
14	18	20	16	20	
11	16	16	20	23	24
13	20	23	23	23	18
12	14	14	14	6	
3	9	5			

- ii) Soil moisture depth at a pressure of 3.0 kg/m² for double nozzle overhead sprinkler.

40					
30					
76	43				
22	20				
18	20	16			
14	16	16			
14	15	16	16		
14	14	14	14		
12	14	14	14	14	
12	16	16	14	16	
10	14	14	16	20	20
10	16	20	20	20	16
8	12	12	12	2	
	5	3			

Appendix A-5 (9)

Catch can data for microsprinkler for an operating pressure of 1.0 kg/cm².

5	6	5	8	8	16	5
4	4	4	6	8	20	6
8	4	4	7	10	18	2
9	8	8	10	15	7	0
11	11	13	11	5	0	0
3	4	3	2	0	0	0

Soil moisture depth for microsprinkler for an operating pressure of 1.0 kg/cm².

3	5	3	6	12	3
3	3	3	5	12	4
6	3	3	6	15	0
7	7	6	8	3	0
8	8	8	9	0	0
2	2	2	0	0	0

Appendix A-5 (10)

i) Catch can data for microsprinkler for an operating pressure of 1.5 kg/cm².

9	3	3	3	2	4	3	3	3
10	2	2	3	3	4	4	3	2
7	4	2	4	4	4	6	4	2
6	5	4	6	6	5	5	2	0
8	6	6	6	5	3	3	0	0
6	6	6	6	4	2	0	0	0
4	5	5	3	3	0	0	0	0

- ii) Soil moisture depth for microsprinkler for an operating pressure of 1.5 kg/cm².

7	2	2	2	1	2	2	2	2
8	1	1	2	1	2	3	2	1
6	2	2	2	2	2	3	2	1
5	3	2	4	3	3	4	1	0
7	4	4	4	2	2	2	0	0
4	4	4	4	2	1	0	0	0
2	3	3	2	1	0	0	0	0

Appendix A-5 (11)

- i) Catch can data for microsprinkler for an operating pressure of 2.0 kg/cm².

11	10	8	6	5	4	3	2
9	11	8	6	6	5	4	3
8	8	6	6	6	4	3	2
4	5	4	3	3	3	2	2
0	3	2	2	2	2	0	0

- ii) Soil moisture depth for microsprinkler for an operating pressure of 2.0 kg/cm².

8	8	7	4	3	3	2	1
6	9	7	4	4	2	2	2
6	6	5	4	4	2	2	1
3	3	3	2	2	1	1	1
0	2	1	1	1	1	0	0

APPENDIX – A 6

Computer software to calculate the UCC , UCC_{abb} , UCC_{sm} , overlapped mean depth of water in catch can overlapped abbreviated mean depth of soil moisture, numbers of sprinklers on lateral line and total annual cost per unit sprinkled area.

```
dimension a (800), b (60, 60), y (60, 60), y1 (60,60)
character * 20 getarag, filnam, filos 21
filo = getarg ( )
filnam = getarg ( )
open (unit = 7, file = 'filos21. txt', status = 'old'
open (unit = 8, file = 'filnam', status = 'new')
write (*,*) 'give no of rows, column for original pattern'
read (*, *) kr, kc
write (*, *) 'give no of rows, column for over lap pattern'
read (*, *) kor, koc
no = kr * kc
read (7, *) (a (j), J = 1, no)
j = 1
500 i = 1
600 iq = 1
    b ( i , j) = 0
120 ip = 1
115 it = i + kor* (ip - 1)
    is = it + kr* koc* (iq - 1) + kr* (j - 1)
    if (it. le. Kr) go to 100
    if ( is . le. (kr * kc)) go to 200
110 if ( i. eq. kor) go to 300
    i = i +1
    go to 600
300 if (j. eq. Koc) go to 700
```



```

j = j + 1
go to 500
100  if (is. le. (kr* kc)) go to 105
      go to 110
105  b ( i , j ) = b ( i , j ) + a (is)
      ip = ip + 1
      go to 115
200  iq = iq + 1
      go to 120
700  do 705 i = 1, kor
705  write (8, 800) (b (i , j) , j = 1, koc)
800  format (8g15.7)
      xx = 0
      p = 0
      do 6 i = 1, kor
      do 6 j = 1, koc
      p = p+1
      xx = xx +b (i, j)
6    continue
      xb = xx /p
      xc = 0
      sd = 0
      do 7 i = 1, kor
      do 7 j = 1, koc
      xc= xc + abs ( b (i,j) - xb )
      s = b ( i , j ) - xb
      sd = sd + s * s
7    continue
      sd = sqrt ( sd / ( p -1.0 ))
      write ( 8,101 ) xb,sd
101  format ( 'mean = ', f10.2,'s.d =', f14.5 )
      ucc = 100* ( 1.- (xc/ xx) )
      write (8,102) ucc

```

```

102  format ('uniformity coefficient (ucc) = ', f10.5)
1700 do 1705      i=1,kor
      do 1705      j=1,koc
          y(i,j)=0
1705  y(i,j) =(i,j)+ ((0.7648)*b(i,j)+ (-0.3750))
      do 1706 i =1,kor
1706  write (8,1710)(y(i,j),j=1,koc)
1710  format (8g15.7)
      yy=0
      py=0
      q=0
      do 8 i =1,kor
      do 8 j=1,koc
          q=q+1
          yy=yy+ (i, j)
8      continue
          yb=yy/q
          yc=0
          sdy=0
          do 9 i =1,kor
          do 9 j=i,koc
              yc=yc+abs(y(i,j)-yb)
              sy=y(i,j)-yb
              sdy=sdy+sy*sy
9      continue
          sdy=sqrt(sdy/(q-1.0))
          write (8,1720)yb,sdy
1720  format ('mean = ',f10.2,'s.d=',f14.5)
          uccy=100*(1. - (yc/yy))
          write (8,1730) ucc
1730  format ('uniformity coefficient (ucc)=',f10.5)
      real ha,di,q,dl,f,k,ns1,ns2,ns
      write (*,*)'Enter head at sprinkler inlet'

```

```

read (*,*)ha
write (*,*)'Enter the inner dia of inner pipe'
read (^, ^) di
write (*, ^) 'Enter the sprinkler discharge'
read ( ^, ^) q
write ( ^, ^) Enter the spacing along the lateral'
read (*, ^) dl
f = 0, 38
k = (1.212e12)
c = 120
r = (q/c)
ns1 = (( 0.2 ha* (di **4.87)) *100)
ns2 = ((f* k* (r **1. 85)) * dl)
ns = ((ns1/ns2) ** 0. 3508)
write (*, ^) 'total numbers of sprinklers on the lateral', ns
l = (ns*dl)
write (*, ^) 'length of sprinkler lateral', l
hf11 = (f* k* ((ns* r) ** 1.85) * ns * dl)
hf12 = ((di** 4.87)* 100)
hf1 = (hf11/hf12)
write (*, ^) 'Enter height of riser'
read (*, ^) hr
hi = (ha +(3/4) * hf1 + hr)
write (*, ^) value of hi ', hi
write (*, ^) 'Enter the cp'
read (*, ^) cp
fc1 = cp* l
write (*, ^) 'Enter the cs'
read (*, ^) cs
fc2 = cs* ns
fc3 = cr* ns
write (*, ^) 'Enter the cr'
read (*, ^) cr

```

```

fc3 = cr*ns
write ( *, *) 'Enter the cc'
read ( *, *) cc
fc4 = cc*ns
crf = (0.118)
write ( *, *) 'Enter the crf '
read ( *, *) crf
fc = (fc1+fc2+fc2+fc4) * crf
write ( *, *) 'Value of fixed cost ' , fc
t = (2920)
write ( *, *) 'Enter the annual use per hour (t) '
read ( *, *) t
ce = (4.50)
write ( *, *) 'Enter the cost of electricity (ce) '
read ( *, *) ce
eae = (1.961)
write ( *, *) 'Enter the cost of ex. Energy (eae) '
read ( *, *) eae
ec = (( 7.35* q/ns) * hi * t * ce * eae ) / 75
write ( *, *) ' The Energy cost is ' , ec
write ( *, *) 'Enter the spacing between laterals '
read ( *, *) dm
tc = (fc +ec) / (1 * dm)
write ( *, *) ' The Total cost is ' , tc
close (7)
close (8)
stop
end

```

Appendix A 7 (1)

Operating pressure: 2.0 kg/cm²

Nozzle type: Single

Range: 9.45 m

Discharge: 0.3 l/sec.

S.No.	Original row x coloumb (mxm)	Δl x Δs (mxm)	UCC catch can (%)	Mean (mm)	UCC _{sm} (%)	Mean (mm)	UCC _{abb} (%)	Mean (mm)	50			75			100		
									Ns	L	Tc	Ns	L	Tc	Ns	L	T
1	20x20	3x5	88.99	389.47	88.99	380.62	94.91	317.63	14	73	12.25	29	146	10.67	48	240	12
2	20x20	6x10	76.88	97.39	76.88	93.72	78.11	46.87	11	115	4.38	23	230	3.72	37	376	4.
3	20x20	8x10	78.35	73.03	78.35	69.82	65.30	34.68	11	115	3.28	23	230	2.79	37	376	3.
4	20x20	9x12	76.82	54.09	76.82	51.22	68.66	34.10	11	129	2.71	21	259	2.29	35	425	2.
5	20x20	12x15	70.48	32.46	70.48	29.97	44.15	27.56	10	149	1.87	20	299	1.58	32	490	1.

Appendix A 7 (2)

Operating pressure: 2.5 kg/cm² Nozzle type: Single Range: 11.45m Discharge: 0.32 l/sec.

S.No.	Original row x coloumb (mxm)	$\delta l \times \delta s$ (mxm)	UCC catch can (%)	Mean (mm)	UCC _{sm} (%)	Mean (mm)	UCC _{abb} (%)	Mean (mm)	50			75			100		
									Ns	L	Tc	Ns	L	Tc	Ns	L	Tc
1	24x22	3x5	95.73	468.27	95.73	459.96	96.61	428.08	15	76	13.33	30	152	10.92	49	249	12.7
2	24x22	6x10	95.86	117.07	95.86	112.94	97.22	95.09	12	119	4.84	24	238	3.84	39	390	4.49
3	24x22	8x10	91.69	87.80	91.69	84.02	84.96	70.64	12	119	3.63	23	238	2.88	39	390	3.37
4	24x22	9x12	84.78	65.04	84.78	61.53	81.14	45.80	11	134	3.00	22	269	2.36	36	439	2.55
5	24x22	12x15	83.08	39.02	83.08	35.83	58.38	30.86	10	155	2.07	21	310	1.63	33	508	1.93
6	24x22	15x20	73.47	23.41	73.47	20.40	54.54	12.29	9	187	1.49	19	374	1.19	31	612	1.41
7	24x22	18x20	77.27	19.51	77.27	16.55	29.68	9.78	9	187	1.24	19	374	1.93	30	612	1.18

Appendix A 7 (3)

Operating pressure: 3.0 kg/cm² Nozzle type: Single Range: 13 m Discharge: 0.38 l/sec.

S.No.	Original row x coloumb (mxm)	Sl x δs (mxm)	UCC catch can (%)	Mean (mm)	UCC _{sm} (%)	Mean (mm)	UCC _{abb} (%)	Mean (mm)	50			75			100		
									Ns			L			Tc		
1	26x26	3x5	97.98	704.33	97.98	689.00	99.36	683.44	14	72	16.79	29	145	11.76	47	237	13.05
2	26x26	6x10	91.37	176.08	91.37	170.94	99.35	169.55	11	113	6.23	23	227	4.18	37	372	4.62
3	26x26	8x10	90.40	132.06	90.40	127.77	89.16	126.73	11	113	4.67	23	227	3.13	37	372	3.46
4	26x26	9x12	94x68	97.82	94.68	94.19	94.47	82.38	11	128	3.86	21	256	2.58	34	419	2.80
5	26x26	12x15	81.45	58.69	81.45	55.82	85.12	44.68	10	148	2.67	20	246	1.78	32	484	1.99
6	26x26	15x40	75.34	35.22	75.34	32.79	68.35	35.26	9	178	1.94	18	351	1.30	29	584	1.46
7	26x26	18x20	79.34	29.35	79.34	27.04	86.35	29.09	9	178	1.62	18	357	1.08	29	584	1.21

Appendix A 7 (4)

Operating pressure: 3.5 kg/cm² Nozzle type: Single Range: 14 m Discharge: 0.44 l/sec.

[illegible]

Appendix A 7 (5)

Operating pressure: 2.0 kg/cm² Nozzle type: Double Range: 9.45 m Discharge: 0.363 l/sec.

S.No.	Original row x coloumb (mxm)	$\delta l \times \delta s$ (mxm)	UCC catch can (%)	Mean (mm)	UCC _{sm} (%)	Mean (mm)	UCC _{abb} (%)	Mean (mm)	50			75			100		
									Ns	L	Tc	Ns	L	Tc	Ns	L	Tc
1	20x22	3x5	94.14	395.67	94.14	391.54	95.95	366.66	13	64	15.93	26	129	12.20	42	212	13.71
2	20x22	6x10	90.71	98.92	90.71	96.19	96.68	86.65	11	101	5.72	20	203	4.24	33	332	4.77
3	20x22	8x10	91.27	74.19	91.27	71.57	77.98	64.42	11	101	4.29	20	203	3.15	33	332	3.51
4	20x22	9x12	84.25	54.95	84.25	52.43	69.47	45.73	10	114	3.53	19	229	2.58	31	374	2.14
5	20x22	12x15	87.72	32.97	87.72	30.55	69.30	23.78	9	132	2.42	18	264	1.78	29	433	2.03

Appendix A 7 (6)

Operating pressure: 2.5 kg/cm² Nozzle type: Double Range: 10.5 m Discharge: 0.472 l/sec.

S.No.	Original row x column (mxm)	δl x δs (mxm)	UCC catch can (%)	Mean (mm)	UCC _{sm} (%)	Mean (mm)	UCC _{abb} (%)	Mean (mm)	50			75			100		
									Ns	L	Tc	Ns	L	Tc	Ns	L	Tc
1	22x20	3x5	95.81	533.67	95.81	533.46	99.74	515.74	12	59	22.92	24	118	13.96	39	193	14.39
2	22x20	6x10	92.37	133.42	92.37	131.89	87.29	107.06	9	92	8.64	19	185	4.94	30	303	5.04
3	22x20	8x10	90.03	100.06	90.03	98.43	75.48	79.80	9	92	6.48	19	185	3.70	300	303	3.78
4	22x20	9x12	85.52	74.12	85.52	72.40	88.54	63.58	9	104	5.36	17	209	3.04	28	391	3.11
5	22x20	12x15	81.45	44.47	81.45	42.65	74.00	36.33	8	120	3.72	16	241	2.10	26	394	2.15

Appendix A 7 (7)

Operating pressure: 3.0 kg/cm² Nozzle type: Double Range: 12.8 m Discharge: 0.556 l/sec.

S.No.	Original row x coloumb (mxm)	δl x δs (mxm)	UCC catch can (%)	Mean (mm)	UCC _{am} (%)	Mean (mm)	UCC _{abb} (%)	Mean (mm)	50			75			100		
									Ns	L	Tc	Ns	L	Tc	Ns	L	Tc
1	26x26	3x5	97.73	791.60	97.73	715.84	97.78	757.22	11	56	31.02	23	113	15.93	37	185	15.12
2	26x26	6x10	91.47	197.90	91.47	178.60	95.31	188.95	9	89	11.74	18	178	5.72	29	290	5.34
3	26x26	8x10	87.94	148.43	87.94	133.83	80.50	141.59	9	89	11.74	18	178	4.29	29	290	4.00
4	26x26	9x12	88.24	109.94	88.24	99.01	84.82	97.45	8	100	7.35	17	200	3.54	27	327	3.30
5	26x26	12x15	85.37	65.97	85.37	59.21	72.73	58.64	8	115	5.13	15	231	2.45	25	378	2.28
6	26x26	15x18	86.85	43.98	86.85	39.32	67.56	31.49	7	130	3.85	14	260	1.85	24	426	1.71
7	26x26	18x20	84.93	32.98	84.93	29.37	86.90	27.98	7	139	3.11	14	279	1.27	23	456	1.38
8	26x26	21x20	82.11	28.27	82.11	25.10	82.49	23.91	7	139	2.66	14	279	1.16	23	456	1.19

Appendix A 7 (8)

Operating pressure: 3.5 kg/cm² Nozzle type: Double Range: 14 m Discharge: 0.640 l/sec.

S.No.	Original row x coloumb (mxm)	5l x 8s (mxm)	UCC catch can (%)	Mean (mm)	UCC _{sm} (%)	Mean (mm)	UCC _{abb} (%)	Mean (mm)	50			75			100		
									Ns	L	Tc	Ns	L	Tc	Ns	L	Tc
1	28x26	3x5	96.35	760.13	97.33	710.48	96.15	692.88	11	54	41.03	21.87	109	18.40	36	178	16.0
2	28x26	6x10	90.30	190.03	90.30	176.69	96.13	172.29	9	85	15.9	17	171	6.74	28	280	5.7
3	28x26	8x10	88.86	142.52	88.86	132.21	90.92	128.91	9	85	11.92	17	171	5.05	28	280	4.2
4	28x26	9x12	91.51	105.57	91.51	97.62	92.27	93.02	8	96	9.93	16	193	4.18	26	315	3.5
5	28x26	12x15	84.05	63.34	84.05	58.08	84.72	51.04	7	111	6.92	15	223	2.89	24	364	2.4
6	28x26	15x18	86.41	42.23	86.41	38.31	80.63	31.72	7	125	5.22	14	251	2.17	23	410	1.8
7	28x26	18x20	85.55	31.67	85.55	28.42	81.55	24.67	7	134	4.20	13	268	1.75	22	439	1.4

Appendix A 7 (9)

Operating pressure: 1.0 kg/cm²

Nozzle type: Microsprinkler

Range: 3.5 m Discharge: 0.0096 l/sec.

S.No.	Original row x coloumb (mxm)	δl x δs (mxm)	UCC catch can (%)	Mean (mm)	UCC _{sm} (%)	Mean (mm)	UCC _{abb} (%)	Mean (mm)	12			16			18		
									Ns	L	Tc	Ns	L	Tc	Ns	L	Tc
1	13x13	2x2	94.51	278	94.51	212.26	94.45	193.14	12	23	2.66	17	49	1.21	28	55	2.82
2	13x13	3x3	93.70	123.56	93.70	94.14	89.21	83.52	10	30	1.33	17	49	1.21	29	72	1.47
3	13x13	4x4	86.69	69.50	86.69	52.80	83.34	39.04	9	36	0.0083	15	59	0.0075	21	87	1.26
4	13x13	5x5	85.65	44.48	85.65	33.67	78.64	32.38	8	42	0.0058	14	69	0.0052	20	101	0.0068
5	13x13	6x6	83.67	30.89	83.67	23.27	87.33	17.11	7	47	0.0043	13	77	0.0039	19	113	0.0053

Appendix A 7 (10)

Operating pressure: 1.50 kg/cm² Nozzle type: Microsprinkler Range: 4.5 m Discharge: 0.0113 l/sec.

S.No.	Original row x coloumb (mxm)	δl x δs (mxm)	UCC catch can (%)	Mean (mm)	UCC _{sm} (%)	Mean (mm)	UCC _{abb} (%)	Mean (mm)	12				16				18			
									Ns	L	Tc	Ns	L	Tc	Ns	L	Tc	Ns	L	Tc
1	15x17	2x2	94.54	229.00	94.54	187.67	93.81	193.02	9	18	4.38	15	30	3.07	23	45	3.08			
2	15x17	3x3	96.19	101.78	96.19	82.95	94.38	78.20	8	24	2.29	13	40	1.55	20	58	1.64			
3	15x17	4x4	91.59	52.25	91.59	46.30	90.98	52.48	7	29	1.48	12	48	0.0099	18	71	1.05			
4	15x17	5x5	94.73	36.64	94.73	29.34	91.79	25.68	7	34	1.05	11	56	0.0069	16	82	0.0076			
5	15x17	6x6	84.75	25.44	84.75	20.12	83.07	17.84	6	38	0.0081	11	63	0.0053	15	92	0.0059			

Appendix A 7 (11)

Operating pressure: 2.0 kg/cm² Nozzle type: Micro sprinkler Range: 3.5 m Discharge: 0.015 l / sec.

S.No.	Original row x column (mxm)	$\delta l \times \delta s$ (mxm)	UCC catch can (%)	Mean (mm)	UCC _{sm} (%)	Mean (mm)	UCC _{abb} (%)	Mean (mm)	12			16			18		
									Ns	L	Tc	Ns	L	Tc	Ns	L	Tc
1	13x12	2x2	94.61	112.51	94.61	94.32	91.69	91.04	9	17	6.41	15	29	3.73	21	42	3.44
2	13x12	3x3	89.53	38.61	89.53	31.85	93.68	39.36	8	23	3.41	13	37	2.01	18	55	1.83
3	13x12	4x4	92.14	30.13	92.14	24.68	78.14	22.19	7	27	2.32	11	45	1.29	17	66	1.20
4	13x12	5x5	85.53	16.54	85.53	13.19	76.32	14.10	6	32	1.65	11	52	0.0093	15	77	0.0087
5	13x12	6x6	84.39	12.31	84.39	9.62	74.31	9.16	6	36	1.28	10	59	0.0071	14	86	0.0068

APPENDIX A - 8

GENERALIZED DATA ON ROOTING DEPTH OF FULL GROWN CROPS, FRACTION OF AVAILABLE SOIL WATER (P) AND READILY AVAILABLE SOIL WATER (p. Sa) FOR DIFFERENT SOIL TYPES (in mm/ m soil depth) WHEN ET_{crop} is 5-6 mm / day

Crop	Rooting depth (d) m	Fraction of available soil water ¹	Reading available soil water (p.Sa) mm / m	
			Medium	Depth of irrigation (mm)
Alfalfa	1.0-2.0	0.55	75	82.5
Banana	0.5-0.9	0.35	50	15.75
Barley ²	1.0-1.5	0.55	75	61.87
Beans ²	0.-0.7	0.45	65	18.9
Beets	0.6-0.1	0.5	70	35.0
Cabbage	0.4-0.5	0.45	65	14.62
Carrots	0.5-0.1	0.35	50	70.50
Celery	0.3-0.5	0.2	25	2.50
Citrus	1.2-1.5	0.5	70	52.50
Clover	0.6-0.9	0.35	50	15.75
Cacao		0.2	30	
Coiton	1.0-1.7	0.65	90	99.45
Cucumber	0.7-1.2	0.5	70	45.00
Dates	1.5-2.5	0.5	70	87.50
Dec. orchards	1.0-2.0	0.5	70	70.50
Flax ²	1.0-1.5	0.5	70	52.50
Grains small ²	0.9-1.5	0.6	80	60.00
Winter ²	1.5-2.0	0.6	80	96.00
Grapes	1.0-2.0	0.35	50	35.00
Grass	0.5-1.5	0.5	70	52.50
Groundnuts	0.5-1.0	0.4	55	22.00
Lettuce	0.3-0.5	0.3	40	6.00
Maize ²	1.0-1.7	0.6	80	81.80
Silage		0.5	70	59.50
Melons	1.0-1.5	0.35	50	26.25
Olives	1.2-1.7	0.65	95	104.97
Onions	0.3-0.5	0.25	35	4.37
Palm tress	0.7-1.1	0.65	90	64.35
Peas	0.6-1.0	0.35	50	17.50
Peppers	0.5-1.0	0.25	35	12.50
Pineapple	0.3-0.6	0.5	65	19.50
Potatoes	0.4-0.6	0.25	30	4.50
Safflower ²	1.0-2.0	0.6	80	96.00
Sisal	0.5-0.1	0.8	110	88.00
Sorghum ²	1.0-2.0	0.55	75	8.25
Soybeans	0.6-1.3	0.5	75	48.75
Spinach	0.3-0.5	0.2	30	3.00
Strawberries	0.2-0.3	0.15	20	0.90
Sugarcane ²	0.7-1.2	0.5	70	42.00
Sunflower ²	1.2-2.0	0.65	90	117.00
Sweet	0.8-1.5	0.45	60	40.00
Potatoes	1.0-1.5	0.65	90	87.75
Tobacco early	0.5-1.0	0.35	50	17.50
Late		0.65	90	58.50
Tomatoes	0.7-1.5	0.4	60	3.60
Vegetables	0.3-0.6	0.2	30	3.60
Wheat	1.0-1.5	0.55	70	57.75
Riponing		0.9	130	175.5
Total available soil water (Sa)			140	

1. When ET_{crop} is 3 mm/day or smaller increase values by some 30%; when ET_{crop} is 8 mm/day or more reduce values by some 30%, assuming non-conditions ($EC < 2$ dS/m).

2. higher values than those shown apply during ripening.

Sources: Taylor (1965), Stuart and Hagan (1972), Salter and Goode (1967), Rijtema (1965) and others.